Parlby Creek - Buffalo Lake Water Management Project

Water Quality Update: 1999-2002

Alberta
Environment

2007-00096

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Water Quality Update: 1999-2002

Prepared for:

Central Region

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Alberta Environment

September 2004

W0403

Pub. No: T/747
ISBN: 0-7785-3762-5 (Printed Edition)
ISBN: 0-7785-3763-3 (On-Line Edition)
Web Site: http://environment.gov.ab.ca/info/home.asp

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EXECUTIVE SUMMARY

A diversion from the Red Deer River to raise the water level in Buffalo Lake began in spring 1996 and has continued through 2002. Diversions are expected to continue each summer until the water level reaches the target elevation. Pre-project water quality studies suggested that algal populations could increase in Buffalo Lake, because the lake's salinity would be reduced by dilution from diversion water. As well, the diversion represents an enhanced nutrient load, which could also increase algal growth in the lake. Thus, there is potential for the degradation of water quality in the lake with the diversion in place, and water quality monitoring has been conducted in all post-diversion years through 2002. The purpose of this report is to update water quality data obtained from sites in Alix Lake and in Buffalo Lake during the summers following the previous water quality update (Mitchell, 1999).

Since 1997, annual diversion volumes have ranged from 6.8 million m^3 (2001) to 15.4 million m^3 (2000). The annual natural surface inflow (March - October) was more than twice the diversion volume in 1997 and 1999, but less than or near diversion volume in 1998, 2000, and 2001, because runoff volumes were lower in these years.

Since the diversion start-up, water quality in Alix Lake has generally been similar to that of Red Deer River water. Some uptake and loss of nutrients does occur through the diversion route to Alix Lake, as well as the addition of some major ions such as sodium. Nonetheless, it appears that the diversion has had a positive effect on Alix Lake water quality from a recreational standpoint, as prior to the diversion, the lake was eutrophic but has remained generally mesotrophic through the post-diversion years. This is likely to continue, contingent on the maintenance of water quality in the Red Deer River.

In Buffalo Lake, Parlby Bay has shown a general improvement in water quality. The enhanced flushing from the diversion has generally reduced salinity, as well as phosphorus and chlorophyll *a* (chl *a*) concentrations in the bay. However, in years of high run-off (e.g., 1999 - 2000), average phosphorus and chl *a* concentrations were higher than in some pre-diversion years. Macrophyte populations have not been evaluated.

In the main lake, general trends in conductivity are similar between Main and Secondary Bays, though are more variable in Secondary Bay. Lake level and inflow volume have a greater influence on salinity in Secondary Bay than in Main Bay. Overall, it is evident that the salinity of the lake has increased over the long term; for a given lake level, conductivity is higher during post-diversion years than in pre-diversion years.

Although dilute relative to lake waters, the diversion represents an increase in ion mass loading to Buffalo Lake. Groundwater input may account for a much larger fraction of the ionic load (e.g., Na, SO_4, and Cl), although estimates suggest that groundwater alone cannot account for the mass loading of ions to the lake. Other local sources include runoff and wind-induced mixing. Some major ions (Ca, Mg, and HCO_3) show a net summer loss in the lake. The most notable of these is calcium, which is probably removed via precipitation to bottom sediments. Other ions, notably Na, SO_4, and Cl, display a net summer increase substantially in excess of the diversion load.

Evaporation of lake waters is a major process influencing the mass and balance of major ions. Given current conditions (i.e., no surface outflow from the lake), it is likely that precipitation of Ca (and increasingly, Mg) will continue, and that major ions such as Na, SO_4 and Cl will become progressively more concentrated in the lake. Hence, salinity will increase over the long term.

Average total phosphorus concentrations in Secondary and Main Bay were higher in the initial diversion years than in previous years sampled. Subsequent values fell generally within the historical range, as did chl *a* values, though mean annual chl *a* displayed a steady decline in Secondary Bay from 1997 through 2002. Post-diversion increases in salinity have not typically produced a concomitant decrease in chl *a* concentrations Overall, algal growth (as chl *a*) appears to respond more to phosphorus concentration than to salinity.

Nutrient loading from the diversion has not measurably affected water quality in Main Bay, because the diversion load is very small compared with the nutrient mass in the lake. Moreover, diversion water (mixed with runoff) passes first through Parlby and Secondary Bays before entering Main Bay; hence, nutrient concentrations are attenuated by dilution, uptake, and loss. For example, in a given year, the amount of total phosphorus contributed by the diversion is only about 3% of the phosphorus mass in Main Bay.

The average amount of phosphorus contributed by the watershed greatly exceeds estimated contributions from other sources, and was > 60% of the average total phosphorus load to the lake for post-diversion years. Similarly, the diversion and internal loads (sediments and/or groundwater) are estimated to be < 5% and 25%, respectively, of the total load to Buffalo Lake. Note that there is considerable variability in these estimates.

Earlier studies have predicted that algal growth in Buffalo Lake could be moderated by changes in salinity. However, in post-diversion years, no consistent relationship is apparent between salinity and chl *a* measurements. Overall, algal growth (as chl *a*) appears to respond to phosphorus concentrations rather than to salinity, although limitations on algal growth could become more apparent as salinity in the lake continues to increase.

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ACKNOWLEDGMENTS

Pat Mitchell of Alberta Environment designed and implemented Buffalo Lake studies for AENV in the first few post-diversion years. She produced a number of reports on Buffalo Lake, providing clear description of the state of water quality in the lake (see references). This report represents an update of her 1999 report.

Staff of Monitoring Branch, including Monica Polutranko, John Willis, Chris Rickard, Rick Pickering, and others collected samples from Buffalo Lake and Parlby Creek and measured flow along the diversion route. Morna Hussey analyzed phosphorus and chlorophyll samples. Chemical analyses were conducted by Maxxam Labs, Inc. and the Alberta Research Council (Vegreville). Microbiological samples were analyzed by the Provincial Laboratory of Public Health. Bridgette Halbig produced graphs, formatted the report, and provided editorial review. Chris Teichreb, Ron Zurawell, and Leigh Noton provided technical review.

1.0 INTRODUCTION

A water management project to designed stabilize Buffalo Lake levels by diverting water from the Red Deer River began in 1985. The objectives were to: 1) stabilize Buffalo Lake levels, 2) provide a reliable water supply for the Village of Mirror, 3) improve agriculture through backflooding, and 4) enhance fish and wildlife habitat (Carson-McCulloch and Golder, 1997). The diversion of Red Deer River water to Buffalo Lake began in the spring of 1996. To monitor potential impacts, an intensive water quality monitoring program was conducted along the diversion and within the two lakes affected by the diversion (Alix Lake and Buffalo Lake). The monitoring continued from 1997 through 2002, although fewer sites were sampled in 1998 and following years.

The monitoring program focused mainly on temporal and spatial changes in nutrient concentrations and salinity in the diversion water between the Red Deer River and Buffalo Lake, and in the lake itself. The potential for increased aquatic plant growth (especially algae) in Buffalo Lake was a concern, should the addition of Red Deer River water lower the salinity of the lake. Although an Environmental Impact Assessment predicted this was unlikely (Environmental Management Associates 1990), two other studies on the lake indicated some potential for higher algal populations to occur (Noton 1984; Brassard and Trimbee 1989). Other concerns included changes in levels of nutrients, metals, bacteria, turbidity, suspended solids and winter dissolved oxygen.

The purpose of this report is to assess the impact of the diversion, and to update water quality information collected since the last report, completed in 1999 (Mitchell, 1999). As noted above, the diversion and lake monitoring program was scaled back after 1997 and involved fewer monitoring sites (see Section 2). As well, results from the 1997 sampling program indicated no significant loading of trace metals via the diversion. Partly because of this, the number of water quality constituents (parameters) analysed in subsequent years was reduced to nutrients, major ions/elements, and "routine" variables such as TDS (total dissolved solids), TSS (total suspended solids), pH, hardness, alkalinity, and carbonate species.

Comparing data for nutrients and ions collected from 1997 to 2002 with those from years prior to the diversion, this report addresses the following specific questions:

- Has the diversion inflow decreased the salinity in Buffalo Lake?
- What is the contribution of phosphorus to the lake from the diversion?
- Has water quality in Alix Lake stabilized in the post-diversion years?
- Is there any change in the amount of algae in Buffalo Lake in recent years (1999-2002) compared with previous years?

As in previous update reports, this report is organized by water quality components such as salinity, nutrients, etc. Within these sections water quality is discussed at sites along the direction of flow, first along the diversion route, including Alix Lake, and then in Buffalo Lake.

2.0 METHODS

2.1 Sampling Sites and Frequency

In 1996-97, samples were collected from several locations along the diversion to document whether water quality was affected by mixing of diversion water with existing water in the conveyance channel (e.g., Parlby Creek; Mitchell, 1999). Fewer sites were sampled in subsequent years, as shown in Table 1.

Table 1 Sites sampled during the Buffalo Lake diversion period (June through October) 1996 through 2002

Site	1996	1997	1998	1999	2000	2001	2001
Red Deer R. at Pumphouse	X	X	X				
Inflow to Alix Lake	X	X					
Alix Lake	X	X	X	X	X	X	X
Alix Lake Outflow	X	X					
Parlby Creek at Alix Gauge		X	X				
Parlby Creek at Mirror	X	X	X				X
Buffalo Lake Parlby Bay	X	X	X	X	X	X	X
Buffalo Lake Secondary Bay	X	X	X	X	X	X	X
Buffalo Lake Main Bay	X	X	X	X	X	X	X
Buffalo Lake Bashaw Bay	X						
Outlet Pond	X						

Sampling sites for all years from 1996 through 2002 are shown in Figure 1a; a summary of each site follows:

1. Red Deer River Pumphouse. Water was collected from the short channel leading to the pumphouse. In 1996, a comparison of data from samples collected simultaneously from the river and the channel indicated very little difference in water quality.
2. Alix Lake Inflow. The water at this point has passed along about eight kilometres of pipeline, channel and two small ponds. In 1996 – 97, samples were collected at a road-crossing culvert immediately upstream of where the diversion flow enters Alix Lake. The purpose of this site is to assess the quality of the water entering Alix Lake.
3. Alix Lake. A small lake (area 0.51 km^2, depth about 3 m) at the town of Alix, used for recreation. There were concerns about the diversion's impact on recreational water quality, since the diversion flushes through the lake. This site has been sampled since 1996 on approximately a monthly basis, from May (or June) through October.
4. Alix Lake Outflow. Samples were collected in 1996 - 97 at the outlet of the lake, downstream of the control structure and gate used to trap debris. This site is located above the point where diversion water joins Parlby Creek.

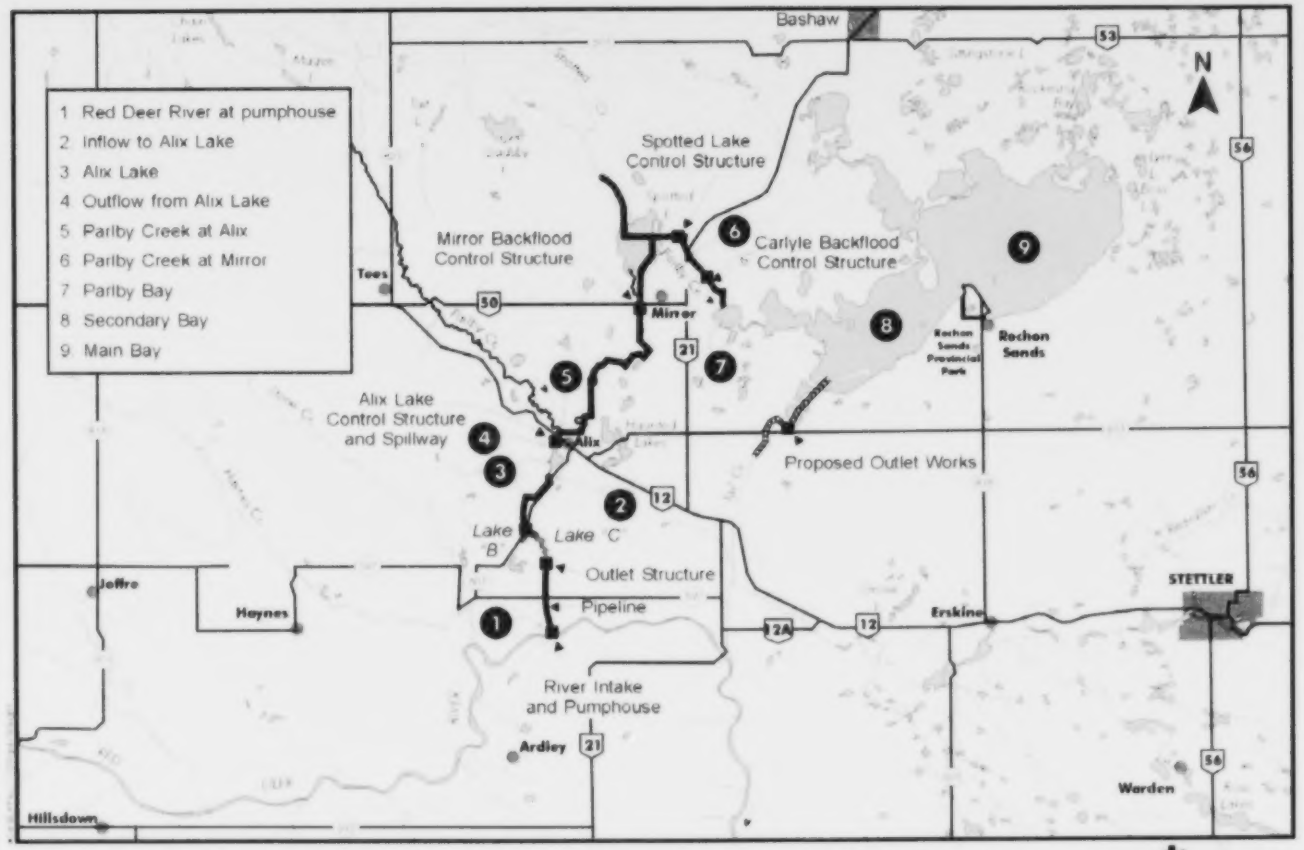


Figure 1. Sampling sites for 1997-98 water quality monitoring program, Parlby Creek - Buffalo Lake.

Figure 1a AENV water quality sampling sites on the Parlby Creek – Buffalo Lake Water Management System: 1996-2002

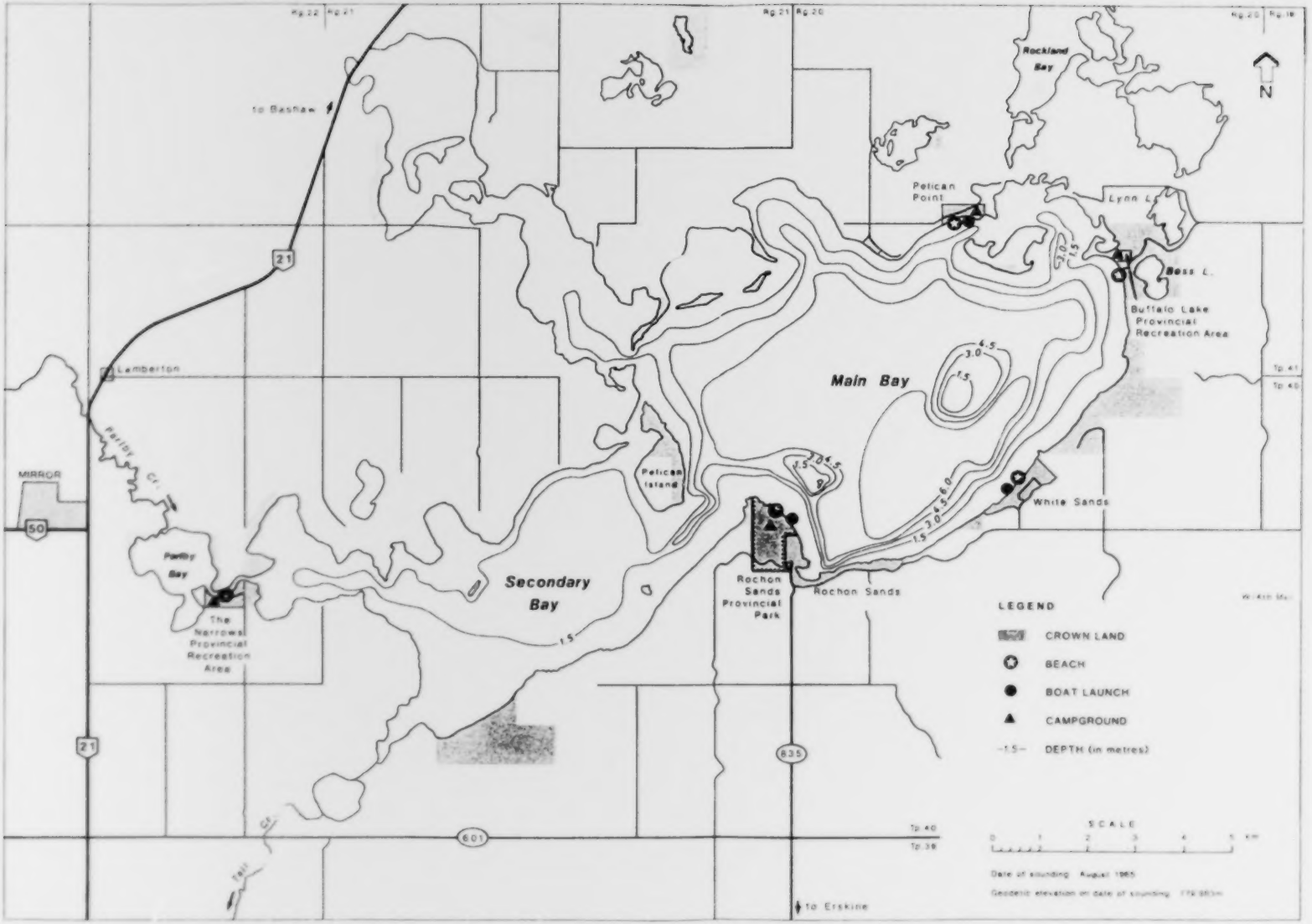


Figure 1b Bathymetry and shoreline features of Buffalo Lake

5. Parlby Creek at Alix. Samples were collected in 1997 - 98 at the federal flow gauge upstream of where Alix Lake outflow joins Parlby Creek.

6. Parlby Creek at Mirror. This is the site of the provincial flow gauge on Parlby Creek, located near Highway 21 north of Mirror. At this point, the diversion has passed through Spotted Lake, and includes natural flow from Parlby Creek. Water from this site should be fairly representative of that entering Buffalo Lake (Parlby Bay), although spring backflooding between the sampling site and the lake may cause some alteration in water quality. This site was sampled in 1996 – 98, and in May 2002.

7. Parlby Bay. This small, marshy bay receives the diversion flow into the lake. It is connected to Buffalo Lake by a channel, called the Narrows. Parlby Bay was sampled approximately monthly during the diversion season from 1996 through 2002.

8. Secondary Bay. The western, shallow portion of Buffalo Lake. Its major inflow comes via Parlby Bay. The bay has been sampled approximately monthly during the diversion season from 1996 through 2002.

9. Main Bay. The largest and deepest basin in Buffalo Lake; it has also been sampled approximately monthly in the diversion season from 1996 through 2002.

2.2 Field Methods

Field methods followed the standard water quality procedures of Alberta Environment (AENV, 2002). Replicate and field blank samples were collected periodically for analytical quality assurance. Sites along the diversion route were sampled by filling bottles directly in the main portion of the flow, or by using a sampling bottle. On each sampling day, Buffalo Lake (Main Bay, Secondary Bay and Parlby Bay) and Alix Lake (Figure 1a) were sampled by lowering a plastic tube from the surface down through the euphotic zone (zone of light penetration, as measured by an underwater light meter). These samples were collected from several locations within each lake area and combined into one sample for the basin. In the deepest area of each basin, dissolved oxygen, temperature, conductivity and pH were measured at one-metre intervals from the surface to the bottom (depth profiles), using Hydrolab™ equipment. Transparency was measured using a Secchi disk. Replicate and field blank samples were collected and analysed periodically to ensure quality control.

2.3 Water Quality Variables

Variables measured at all sites included conductivity, pH, temperature, dissolved oxygen, major elements & ions, alkalinity, hardness, total dissolved solids (TDS), total suspended solids (TSS), silica, phosphorus (total and dissolved), nitrogen fractions (NO_2-NO_3, ammonia, NH_3, and total kjeldahl nitrogen; TKN), and total organic carbon (TOC). Transparency, light penetration and chl *a* were measured at all lake sites. In addition, monthly depth profiles were conducted in each major lake basin during each summer season through 2001. Late winter depth profiling was done on March 1, 2000.

In May 2002, a sample was collected from Parlby Creek at Mirror (Site 6) for the discreet parameters listed above, as well as for fecal coliform bacteria and *E. coli*, a specific intestinal fecal coliform bacterium.

2.4 Hydrology

Flow volume was measured at the pumphouse, and continuous discharge was recorded at the provincial gauging station on Parlby Creek near Mirror (Station 5CD902) and the federal gauging station on Parlby Creek at Alix (Station 5CD007).

A weekly water balance for Buffalo Lake was completed based on a detailed mass balance of the Buffalo Lake system (accounting for evaporation), which extended from 1984 to 1997 (Douglas 1998). Watershed runoff for the 1998 through 2002 seasons was calculated by estimating the monthly basin yield for the Parlby Creek basin (excluding the flow volume from the diversion). This was extrapolated to the remainder of the Buffalo Lake watershed using the same proportion of Parlby basin runoff to total basin runoff as Douglas (1998) used for pre-1998 data.

Water volumes for Main and Secondary bays were based on an area-capacity curve in W-E-R Engineering (1990) and water level–capacity relationships in Douglas (1998). The water volume for Parlby Bay was estimated from surface area and approximate depth, using the assumption that lake volume increases proportionately to increases in water level.

2.5 Data Analysis

To compare the total mass of various substances in the lake for each year sampled, concentrations of constituents measured in September were multiplied by the total water volumes in Parlby Bay, Secondary Bay and Main Bay. Daily measured flows are available for Parlby Creek at Mirror and Parlby Creek at Alix. However, water quality data was generally not collected for Parlby Creek in the years subsequent to 1998. Hence, mass loads from the diversion for these years were calculated based on scaled data for Alix Lake.

Phosphorus loads for Secondary Bay and Main Bay were calculated from the mass increase of phosphorus in each bay over the summer using a simple mass balance equation, e.g.:

Internal Load = Change in mass in bay – Inputs to bay + Loss from bay

The change in mass was estimated from the amount of phosphorus in the lake when the concentration is typically lowest (June) and when the concentration is highest (September). The phosphorus entering the bay over this period was then subtracted. The contribution from Parlby Bay was estimated with the flow volume from Parlby Creek at Mirror, and Parlby Bay total phosphorus concentrations during the time period. Similarly, the contribution to Main Bay from Secondary Bay was estimated with the same inflow volume and Secondary Bay phosphorus concentrations. The loss from Secondary Bay was included in the equation for that bay, but it was assumed there would be minimal advective loss from Main Bay. Contributions from sewage and from (or to) groundwater were not specifically accounted for; i.e., these were included in the internal loading estimate.

Data from euphotic composite samples were used to represent the concentrations of variables used in the mass balance calculation. Although water below the euphotic zone may at times be more concentrated in some variables (e.g., P and N), most of the water mass in these basins is

within the euphotic zone. Hence, the use of euphotic composite data is not thought to introduce significant error in the mass balance calculations.

3.0 RESULTS OF THE 1999 – 2002 MONITORING PROGRAM

Historically, the primary focus of water quality monitoring programs on Buffalo and Alix lakes has been the assessment of concentrations of plant nutrients such as phosphorus. Phosphorus concentration is directly related to the potential for aquatic plant growth, specifically shoreline vegetation (macrophytes) and suspended algae (phytoplankton). An increase in the capacity of the lake to produce plants could lead to nuisance algal blooms, decreased levels of dissolved oxygen in winter, the threat of fish kills, higher turbidity, and a general decline in recreational water quality. A lake characteristic related to this is salinity, as high salinity has been linked with suppressed algal growth in prairie lakes (e.g., Bierhuizen and Prepas 1985). Salinity is indicated by measurements of conductivity or total dissolved solids. Also included in the monitoring program was an assessment of the dissolved oxygen concentrations in Buffalo Lake.

3.1 Inflow Volumes and Lake Level

Pumping at the Red Deer River diversion typically commences in May or June and runs through October. Total flow volumes over this period are shown in Table 2.

The volume of Alix Lake is small relative to the total amount of diversion water entering it. As a result, it is frequently flushed during the diversion period. Based on diversion period volumes, the lake has flushed, on average, about 16 times in a given year (ranging from about nine times in 2001 to 19 times in 2000).

Table 2 Buffalo Lake pumphouse – water volumes (m^3) for 1997 to 2002

Month	1997	1998	1999	2000	2001	2002
May	--	--	2,291,800	2,750,200	--	277,900
June	2,203,244	1,847,400	3,358,800	1,683,800	682,500	2,444,000
July	2,340,868	1,305,100	415,200	971,600	824,800	3,221,700
August	3,184,087	3,490,800	667,500	2,962,800	734,400	3,398,500
September	2,868,863	3,735,500	3,086,800	3,412,500	2,276,000	3,166,900
October	3,335,608	84,100	3,318,200	3,575,000	2,265,700	2,877,100
Total Diversion	13,932,670	10,462,900	13,138,300	15,355,900	6,783,400	15,386,100

Parlby Bay, with a somewhat smaller water volume, has flushed more frequently during the diversion period. However, in Secondary Bay the inflow volume during the diversion period ranged from about 19% (in 2001) to 62% (in 1999) (average of 39%) of the bay volume, which indicates that it is not completely flushed in one diversion season. This water renewal rate is fairly rapid compared with most central Alberta lakes (Mitchell and Prepas, 1990). In Main Bay, the volume of water assumed to have entered from the diversion and from natural runoff in Parlby Creek ranged from about 3% (in 2001) to 11% (in 1999) (average of 7 %) of the bay volume during the diversion months. Including the additional water supplied by the diversion, the water renewal time for Buffalo Lake is estimated to be approximately 11 years. Without the diversion, this would increase to about 24 years (Mitchell, 1999).

Because the water level has remained below the outlet sill, water leaves the lake primarily by evaporation. Groundwater outflow has been suggested, based on discrepancies between measured and predicted lake salinity. However, there are no known areas of groundwater seepage from the lake (Envir. Mgt. Assoc., 1990). Since the greatest inflow is on the west end of the lake, water likely passes from Parlby Bay to Secondary Bay to Main Bay during periods of high inflow. During 1999 and 2000, the water level of Buffalo Lake was notably high compared with other years (Figure 2), due only in part to the diversion. As illustrated in Figure 3, local runoff contributes a substantial volume of water relative to the diversion. For example, between March and October of 1997, the diversion contributed 14 million m^3 (Mm^3) whereas local runoff contributed 42 Mm^3 of water to the lake (Douglas, 1998), three times the diversion volume. Similarly, in 1999 local runoff contributed over four times the diversion volume to the lake. However, in 1998 and 2001 the volume of annual natural runoff (8.8 and 6.1 Mm^3, respectively) was lower than the diversion volume (10.5 and 6.8 Mm^3, respectively).

The maximum mean monthly lake elevation achieved during 1997 through 2002 was 780.78 m, in June 2000. The post-diversion target elevation is 780.85 meters[1]. Based on the area of the lake in summer 1997 (103 Mm^2), if all of the diversion water for that year (14 Mm^3) were added to Buffalo Lake at once, the increase in lake level would be about 0.135 m. This implies that a threshold input flow volume may exist such that lake levels would be sustained or increased, as apparent in the lake levels sustained through 2000 (i.e., net loss of water is balanced by inflow volume). However, losses through the system and evaporation, which vary seasonally and annually, act to reduce diversion contributions to lake volume.

3.2 Salinity and Major Ions

All water quality data for the study period are listed in Appendix A. The salinity of water is indicated by total dissolved solids (TDS) concentration and by electrical conductivity. Eight major ions typically contribute to the salinity of Alberta surface waters: calcium, magnesium, potassium, sodium, chloride, bicarbonate, carbonate and sulphate. Dominant ions in Buffalo Lake include sodium, sulphate, and bicarbonate.

3.2.1 Diversion Route and Parlby Creek

The water chemistry of the Red Deer River diversion and Parlby Creek at Mirror was evaluated in previous reports (e.g., Mitchell, 1999). In the initial diversion years, water from the Red Deer River increased in TDS as it mixed with water in ponds, Alix Lake, Parlby Creek, and Spotted Lake, prior to entering Buffalo Lake. However, slight decreases in some constituents such as hardness, conductivity, sodium, sulphate in Parlby Creek were noted in samples collected in 1997 relative to 1996. This indicated that water quality in Parlby Creek at Mirror more closely resembled that of the Red Deer River as lakes and ponds along the diversion route were flushed

1 Note that there has been no surface outflow from Buffalo Lake since 1929 (Mitchell and Prepas, 1990).

Figure 2a Lake levels in Buffalo Lake near Erskine (05CD005) and annual precipitation (near Mirror), 1965 – 2002

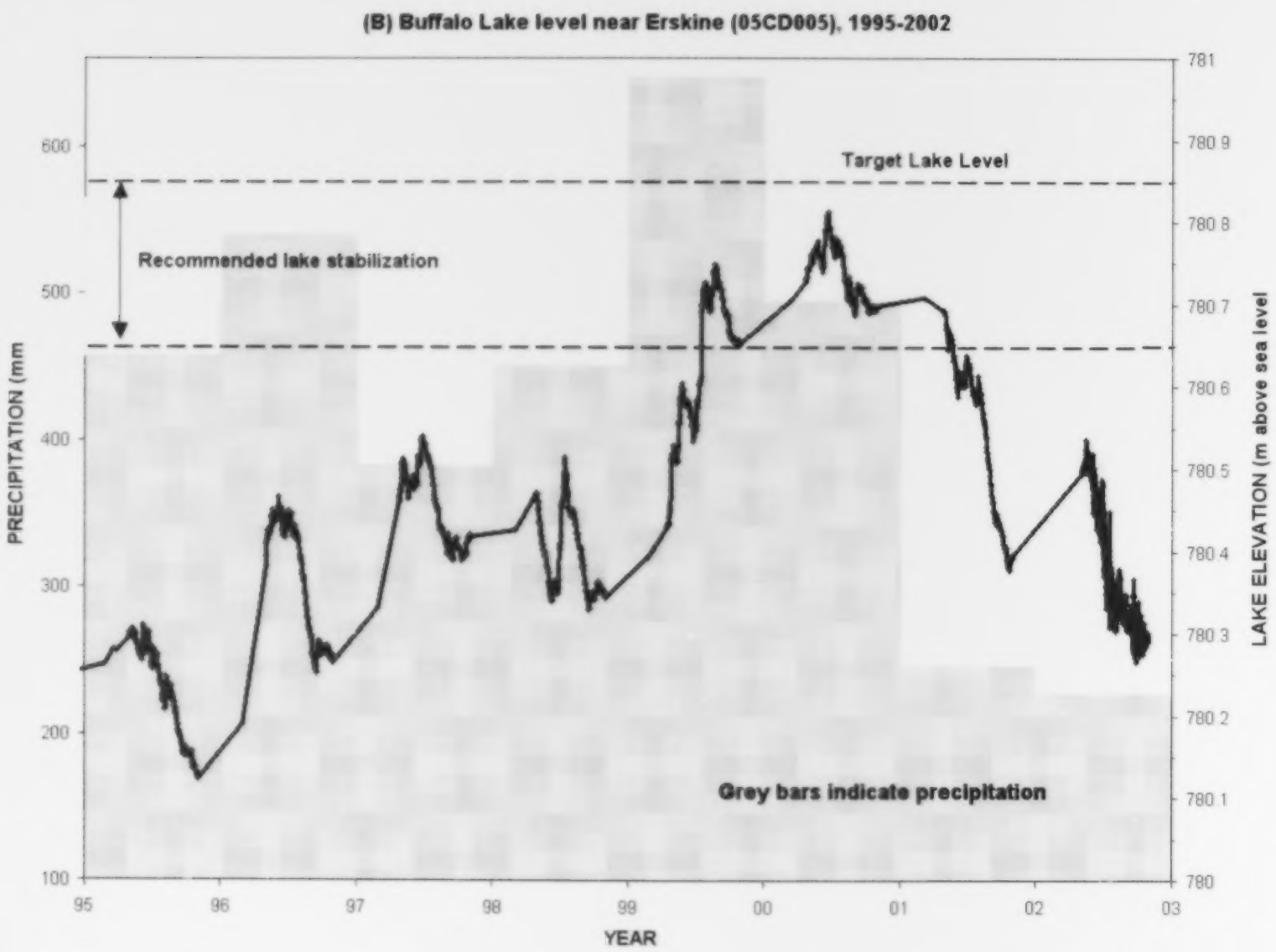


Figure 2b Lake levels in Buffalo Lake near Erskine (05CD005) and annual precipitation (near Mirror), 1995 – 2002

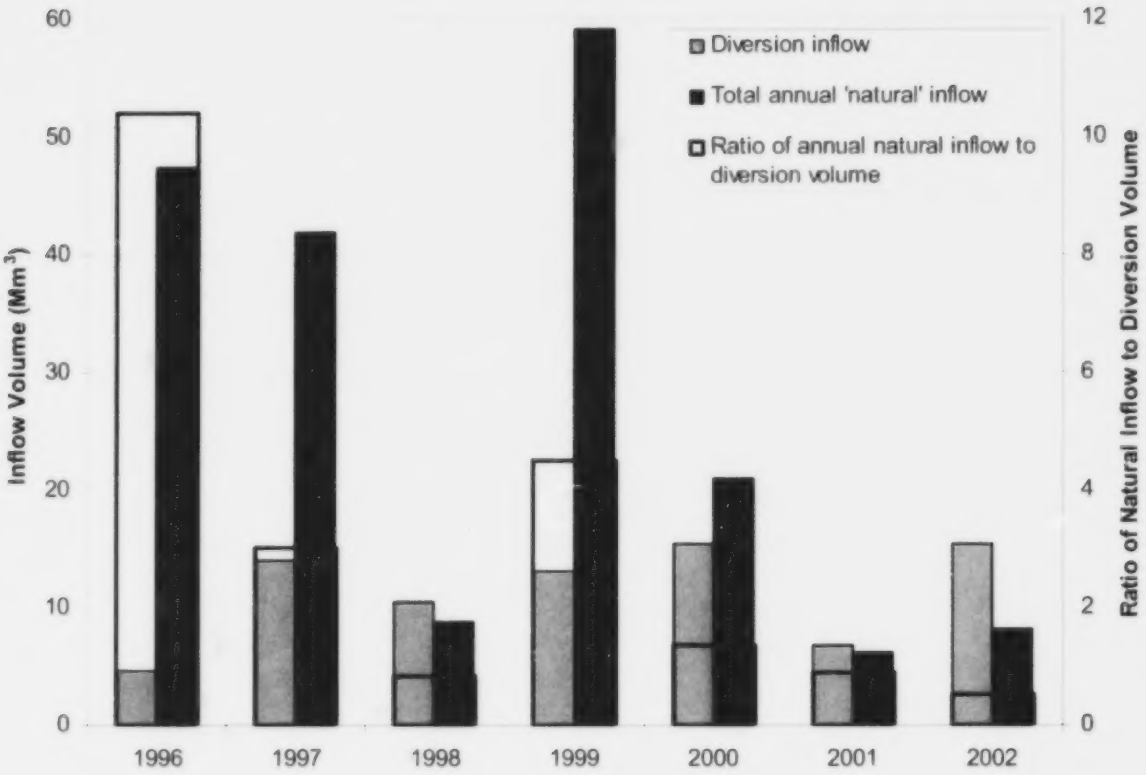


Figure 3 Estimated inflows to Buffalo Lake, 1996 to 2002

with diversion water. Note, however, that concentrations of several constituents in the Red Deer River also declined somewhat over this period.

Based on mass load calculations (i.e., quantity of a substance over time), Mitchell (1999) determined that constituent contributions along the diversion route were declining, even though mass loads from the Red Deer River had increased with higher diversion flow volumes. Moreover, no substantial additions or losses of water or major ions were apparent through the diversion system, probably due to flushing with low-salinity water. Hence, in the initial diversion years, there appeared to be some flushing out of salinity (from existing sloughs and perhaps salty/alkali land) through the diversion route. Over time, this phenomenon seemed to diminish as the salts were flushed out, and the diversion system came to more closely resemble the Red Deer River in water quality. Some minor discrepancies are apparent in the mass balance between Parlby Creek at Mirror and Red Deer River – Alix Lake, which could be due to the timing of sample collection, data averaging, and annual variability in run-off loads (e.g., higher TDS loading in wet years than in dry years). On average, the concentrations of major ions in Alix Lake from 1997 through 2002 were similar to those in Red Deer River water. However, increases in some ions are apparent through the diversion system in the post-diversion years. For example, sodium (Na), potassium (K), and chloride (Cl) display average annual concentrations in Alix Lake of up to 1.5 times that of Red Deer River water (Table 3).

Note that the 2002 sample collected from Parlby Creek at Mirror (May 29) represents water quality in Parlby Creek during the commencement of pumping, and was similar to spring water quality samples collected in prior years at that site. This may reflect remnant winter conditions, which are typically higher in conductivity and ion concentrations relative to samples collected during active diversion periods.

3.2.2 Buffalo Lake

Water chemistry data for sites in Buffalo Lake from 1997 through 2002 are shown in Table 4. Concentrations of TDS, conductivity, and other chemical constituents have generally decreased in Parlby Bay since 1995, except calcium concentrations, which were episodically higher in some post-diversion years (e.g., '97, '99, and '00), than in 1995 before the diversion began. In 1998, concentrations of routine chemical variables were still somewhat higher in Parlby Bay than in Parlby Creek at Mirror. Chemical processes in bottom sediments, carbonate equilibria, and evaporative losses of water may act to maintain these higher levels.

A long-term representation of salinity in Main and Secondary bays is presented in Figure 4, which shows median conductivity for all years for which there are data. In both Main and Secondary Bays, conductivity in the years following the diversion is within the historical range. Over the longer-term, general trends in conductivity are similar between Main and Secondary Bays, though Secondary Bay displays considerable year-to-year variability. That variability may reflect its proximity to the main inflow. Note that conductivity declined in Secondary Bay between 1995 and 1996, though a continuing decline was not apparent in the ensuing years. This transitory decline is in accord with predictions that conductivity would decrease by 15 to 20% during the initial years of the project, but would continue to become more saline over the long term (Goudey et al., 1990). In Main Bay, annual differences are attenuated, as would be expected with the small inflow volume relative to the volume of the bay. Hence, in any given year, lake level and inflow volume have a greater influence on salinity in Secondary Bay than in the larger Main Bay. As well, the more persistent trends in conductivity appear to lag by about a year behind those of Secondary Bay.

It is likely that the movement of relatively dilute waters from Secondary Bay has some effect on the salinity of Main Bay. There is little information available on water movement between bays[2], although water quality data does provide some evidence that mass loading from diversion waters is reflected in the chemistry of Main Bay. Given that the main inflows are to Secondary Bay, there would have to be some net annual movement of water from there to Main Bay.

In the historical data, there is a significant inverse relationship between water level and salinity in Buffalo Lake, with an apparent increase in conductivity concurrent with declining lake levels through the seventies and eighties (Figure 2). This probably reflects evaporative concentration of dissolved solids. Conductivity remained high, corresponding with low (though stable) lake

2 Previous studies have suggested that wind-induced mixing between basins does occur, and that water entering Parlby Bay can move into Main Bay within about a month (Norecol Env. Cons., 1984).

Table 3 **Average concentrations of major ions and related variables for the Red Deer River and Alix Lake diversion during the diversion period (June through October) 1996-2002**

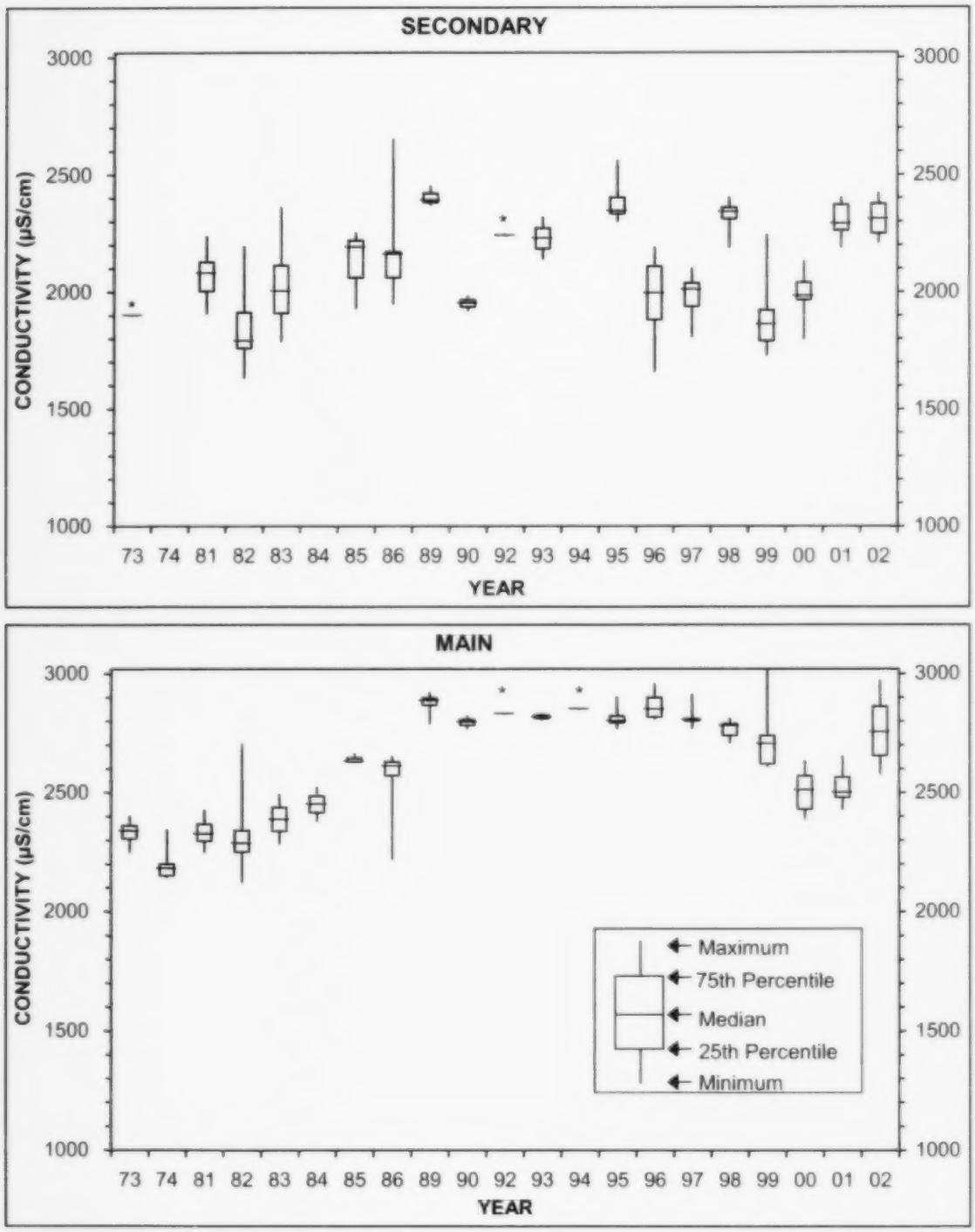
	Red Deer River at Pumphouse			Red Deer River @ Nevis				Parlby Creek at Mirror			
	1996	1997	1998	1999	2000	2001	2002	1996	1997	1998	2002
pH (range)	8.05-8.80	7.64-8.73	7.65-8.57	7.93-8.54	8.17-8.58	7.80-8.71	8.42-9.07	8.11-9.05	7.12-9.19	8.14-9.40	8.31
Conductivity, µS/cm	361	359	328	355	366	332	306	494	431	410	712
Total Suspended Solids, mg/L	5	8	54	65	28	65	3	4	5	2	3
Total Diss. Solids, mg/L	204	205	193	215	209	195	170	292	255	245	457
Calcium, mg/L	47	45	44	47	43	40	34	39	39	38	59
Magnesium, mg/L	15	15	15	16	16	14	14	26	21	21	32
Total Hardness, mg/L	177	174	171	182	170	158	144	204	181	179	280
Sodium, mg/L	11	11	9	13	14	12	7	36	28	29	60
Potassium, mg/L	1.7	1.7	2.2	2.3	2.4	2.0	1.1	4.4	3.1	3.8	7.8
Sulphate, mg/L	31	30	25	28	32	34	38	48	42	30	112
Chloride, mg/L	2.7	3.6	1.9	3.3	3.4	3.6	2.3	4	5	4	11
Total Alkalinity, mg/L as $CaCO_3$	160	161	154	172	162	144	126	221	193	196	281
Bicarbonate, mg/L	189	183	182	207	197	170	135	250	217	224	333
Carbonate, mg/L	3	7	4	2	1	3	6	10	9	8	5
Number of Samples	12	11	7	5	5	5	5	12	11	7	1

	Alix Lake						
	1996	1997	1998	1999	2000	2001	2002
pH (range)	8.32-8.77	8.05-8.42	7.81- 9.19	8.04-8.32	7.79-8.31	8.00-8.38	8.23-8.87
Conductivity, µS/cm	408	354	297	356	338	313	311
Total Suspended Solids, mg/L	1	1	3	1	2	1	1
Total Diss. Solids, mg/L	234	203	167	202	195	181	182
Calcium, mg/L	33	37	26	32	30	29	28
Magnesium, mg/L	24	19	16	18	17	18	16
Total Hardness, mg/L	180	173	134	154	146	148	137
Sodium, mg/L	22	15	13	16	18	15	15
Potassium, mg/L	3.9	2.6	2.4	2.7	3.4	2.1	1.7
Sulphate, mg/L	42	34	28	36	36	38	39
Chloride, mg/L	3	4	3	5	5	4	5
Total Alkalinity, mg/L as $CaCO_3$	175	151	125	149	141	133	128
Bicarbonate, mg/L	207	181	143	180	171	161	147
Carbonate, mg/L	4	2	4	1	1	1	7
Number of Samples	6	6	5	5	5	4	3

Table 4 Average concentrations of major ions and related variables for Alix Lake and Buffalo Lake, June-October 1995 to 2002
Number of samples = 3 to 6 for each area per year. Units are mg/L except where indicated otherwise.

	Alix Lake							Parlby Bay						
		97	98	99	00	01	02	95	97	98	99	00	01	02
pH (range), pH units	--	8.05-8.42	7.81-9.19	8.04-8.32	7.79-8.31	8.00-8.38	8.23-8.87	8.49 - 9.84	8.31-9.58	8.21 - 9.25	8.04-8.81	8.18-8.37	8.32-9.40	8.50-8.60
pH (mean), pH units	--	8.35	8.30	8.23	8.02	8.32	8.50		8.86	9.01	8.57	8.26	8.86	8.51
Conductivity, µS/cm	--	354	297	356	338	313	311	721	491	550	574	557	529	326
Total Diss. Solids	--	203	167	202	195	181	182	447	292	310	342	327	293	188
Calcium	--	37	26	32	30	29	28	30	38	28	41	41	27	28
Magnesium	--	19	16	18	17	18	16	36	24	24	25	25	25	17
Total Hardness	--	173	134	154	146	148	137	223	193	170	204	206	170	137
Sodium	--	15	13	16	18	15	15	92	41	56	50	45	67	18
Potassium	--	3	2	3	3	2	2	9	5	6	6	6	6	2
Sulphate	--	34	28	36	36	38	39	73	47	47	52	49	60	41
Chloride	--	4	3	5	5	4	5	8	4	5	7	7	6	4
Total Alkalinity ($CaCO_3$)	--	151	125	149	141	133	128	333	217	235	260	248	245	131
Bicarbonate	--	181	143	180	171	161	147	315	232	233	294	300	246	150
Carbonate	--	2	4	1	1	1	7	45	16	26	11	2	26	5
	Secondary Bay							Main Bay						
	95	97	98	99	00	01	02	95	97	98	99	00	01	02
pH (range), pH units	9.16 - 9.30	8.96 - 9.13	9.00 - 9.11	8.78-8.95	8.88-9.00	8.80-9.18	9.09-9.16	9.29 - 9.32	9.13 - 9.31	9.08 - 9.22	9.02-9.07	8.94-9.04	8.85-9.23	9.22-9.28
pH (mean), pH units		9.05	9.06	8.89	8.92	9.13	9.13		9.23	9.16	9.05	8.98	9.17	9.25
Conductivity, µS/cm	2428	1982	2317	1815	1986	2307	2313	2825	2817	2767	2647	2517	2532	2764
Total Diss. Solids	1673	1300	1460	1185	1388	1653	1565	1980	1900	1826	1698	1810	1831	1956
Calcium	9	15	9	15	13	10	11	5	7	7	6	7	7	6
Magnesium	77	60	63	53.3	62.26	71.333	63	80	80	77	71	75	76	72
Total Hardness	336	284	282	255	290	323	293	363	349	336	303	330	330	310
Sodium	502	363	421	324	434	507	482	607	572	529	499	577	571	627
Potassium	37	32	34	27	33	40	34	43	44	42	39	42	44	42
Sulphate	414	315	369	290	323	410	383	508	463	469	390	446	466	469
Chloride	15	14	15	13	15	17	17	16.3	18	17	17	17	17	19
Silica	2.1	4.34	1.95					1.2	1.63	0.94				
Total Alkalinity ($CaCO_3$)	1033	823	914	765	843	984	961	1194	1179	1142	1126	1068	1079	1196
Bicarbonate	950	791	862	709	765	852	890	1051	1046	1001	976	950	914	1033
Carbonate	152	104	124	110	130	172	139	199	190	192	195	174	198	208

Note: shade indicates pre-diversion



Note: * indicates only one sample

Figure 4 Conductivity in Buffalo Lake, April to September: 1973 to 2002

levels from 1989 through 1995, and decreased as lake levels generally rose through 2000. Enhanced inflow of fresher water, due to the diversion and high runoff, likely suppressed the salinity increase to some extent in these years. During 2001 and 2002, conductivity increased again as lake levels dropped.

Over the long term, or at least since the high-water years of 1974 -75, the salinity of the lake has generally increased. This will likely continue until such time as the water level becomes high enough for discharge to occur at the outlet. The conservative major ions of the lake's inflowing waters have no way to leave the lake and are likely to remain, subject to solubility constraints (e.g., precipitation of marl ($CaCO_3$)). Loss to groundwater is unlikely, because the static head of aquifers is higher than the lake elevation (Crompton 1984). Previous work has suggested that the diversion may not reduce salinity in Buffalo Lake, though may moderate the rate at which salinity increases (Mitchell, 1999; Crompton 1984).

As noted above, an inverse relationship exists between conductivity and lake levels. However, for a given lake level, conductivity is higher during post-diversion years (1996-2002) than in the pre-diversion years from 1983 to 1995 (Figure 5)[3]. This could reflect the fact that in pre-diversion years, water inflows were generally more dilute as a result of there being a greater proportion of snow melt in the inflows. The high snow pack years of the early to mid 1970's may have been a factor in this. In the diversion period, Red Deer River water, with a higher TDS than snow melt, is specifically added to the lake to make up for the lower amounts of natural runoff. Further, there may have been some flushing of salts from the diversion system in its initial years of operation.

The calculated mass of major constituents in each basin of Buffalo Lake for the post-diversion years is presented in Appendix B. These mass loads are based on September data for each year, after the bulk of the diversion water has entered the lake. The relative mass of some substances has fluctuated significantly from year to year, likely owing to variable runoff and input loads, to mixing processes within and among basins, and to changing chemical equilibria. In addition, uncertainty in lake volume estimates and measurement error in concentration values may also influence mass estimates. Notwithstanding such uncertainty, significant inter-annual variability in constituent mass corresponds with changes in lake level, itself influenced by total inflow to the lake. For example, the peak inflow volumes in 1999 - 2000 correspond with increased masses of Na, SO_4, Cl, Mg, and other ions. In 1999 (year of the largest post-diversion inflow volume), a substantial increase in constituent mass was apparent in Parlby Bay; however, a corresponding increase was not evident in Secondary or Main Bay until 2000. This delay in mass loading may reflect the longer time required for mixing to occur through the volume of the main lake.

The actual mass of most constituents in the lake has not shown a progressive decline through post-diversion years, as might be expected. One factor contributing to this is constituent loading via the diversion. Although the inflow water is generally dilute relative to lake waters, the diversion represents a net increase in mass loading to Buffalo Lake, as suggested in Figure 5.

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3 Significant @ 99% confidence, based on Wilcoxon Rank-Sum Test (median difference approximately 170 uS/cm).

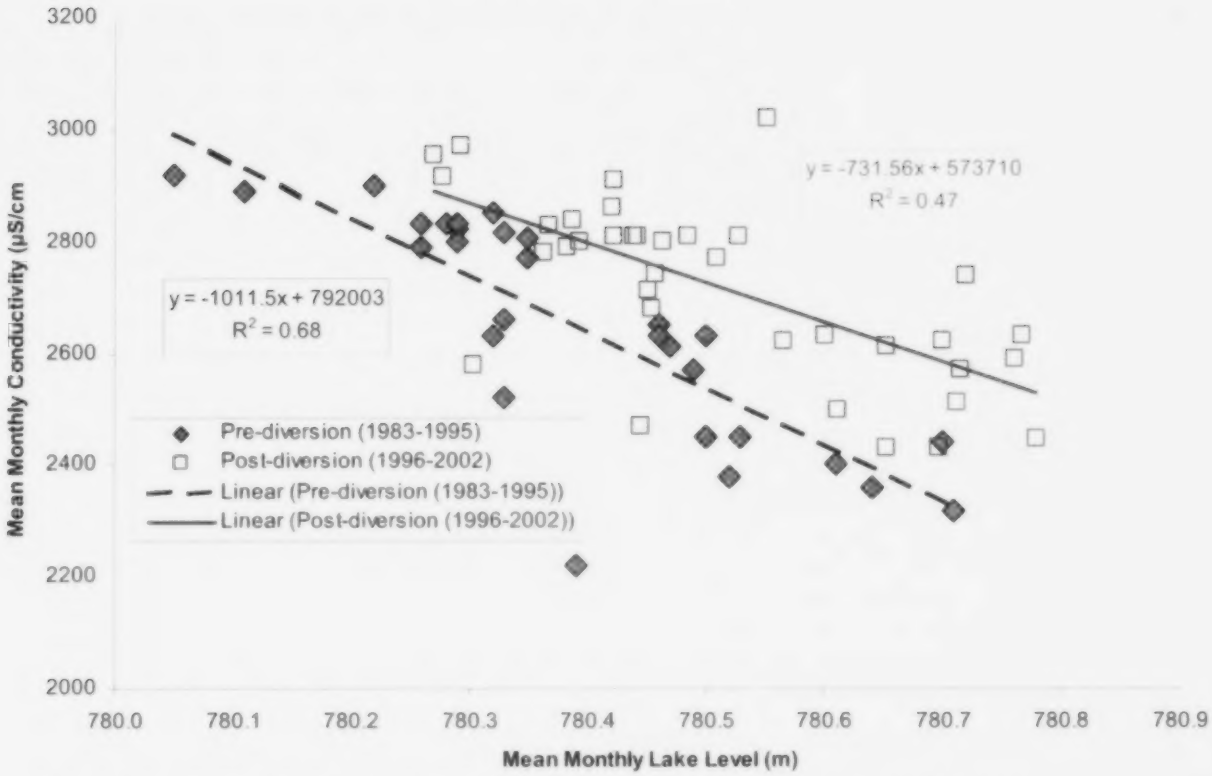


Figure 5 Conductivity (Main Bay) vs. Lake Level in Buffalo Lake, 1983 to 2002

Table B2 (Appendix B) shows the change in constituent mass for the lake basins in fall (September), relative to spring (June). Using TDS as an example, Parlby Bay received an annual average of about 3.3 million (M) kg of TDS from Parlby Creek in May – October from 1997 to 2002. However, the September TDS mass in the Bay remained at an average of about 0.1 Mkg, indicating that approximately 3 M kg of TDS may pass to Secondary Bay each year, though certain substances such as calcium may precipitate out to the bottom sediments, thereby reducing the TDS mass.

Based on primary chemical characteristics, such as ambient pH and alkalinity in Secondary and Main Basins, some Ca precipitation is likely to occur (Stumm and Morgan, 1981). Also, the relatively high Na concentrations may influence Ca concentration, due to the well-known common ion effect (e.g., the presence of excess $NaHCO_3$ would decrease the concentration of Ca^{2+} in equilibrium with calcite; Stumm and Morgan, 1981). Calcium removal/precipitation in Buffalo Lake is apparent in Ca concentrations, which are typically 2 to 3 times lower in Secondary Bay, and about 5 times lower in Main Bay compared to Parlby Creek. In addition, the net change in the whole-lake Ca mass during the diversion period of 1997 to 2002 was generally negative, with the exception of 2000. Interestingly, 2000 experienced the lowest September pH, and followed the year with the highest post-diversion total inflow. Overall, most of the total diversion Ca load was lost through summers of the post-diversion years (diversion Ca load

compared with summer lake change; Table B3, Appendix B). Moreover, the relative mass of Ca transported via the diversion was higher than for other major ions. The average annual Ca mass diverted at the pump house was about one-third of the September Main Bay mass, and near 100% of the September Secondary Bay mass. In addition, the entire the Ca load at Mirror can be accounted for by the mass delivered via the diversion (i.e., through the pump house).

There was also a net summer loss from the lake of other major ions, such as Mg and HCO_3, which is substantially greater than the mass delivered via the diversion. For the post-diversion years from 1997 to 2002, the diversion load of these ions constituted a very minor fraction (relative to Ca) of their September Main and Secondary Bay masses, at about 1% each. In these years, a total net summer loss of HCO_3 from the lake (~50 Mkg) was balanced, in part, by a corresponding increase in CO_3^{2-} (~40 Mkg), suggesting a shift in inorganic carbon equilibrium through the summer. Summer increases in lake pH, which have often exceeded values of 9, would account to some degree for a shift in ambient carbonate species. However, an increase in mean annual lake pH was not apparent, and alkalinity has remained relatively constant in post-diversion years. Nonetheless, a steady decrease in September HCO_3 relative to alkalinity was evident in post-diversion years, notably in Secondary Bay (Figure B1, Appendix B). This decrease was not as apparent in Main Bay, and additional years of data are required to more clearly identify such trends.

Other ions, notably Na, SO_4, Cl, and K displayed a net summer increase in post-diversion years that was substantially in excess of the diversion load. Alternate sources that could account for this increase include natural runoff and groundwater. Groundwater inflow to the lake is significant, and has been estimated at approximately the volume of annual surface inflow (Shaw and Prepas, 1990). Artesian upwelling occurs at the west end of the lake, along the north shore of Secondary Bay, and in Main Bay (e.g., Mitchell and Prepas, 1990). Groundwater influx could be accounted for to some degree by fluctuating lake levels, as apparent for example, in substantial changes in net annual Na loading during the years of large lake level fluctuations (e.g., 2000 to 2002). Groundwater influx is highly variable, depending on lake level and annual precipitation (Clare, 2004); hence the input of major ions via groundwater will vary accordingly. However, utilizing the bulk estimate (above) for groundwater inflow and approximate values for groundwater chemistry (Clare, 2004), the groundwater ion load for post-diversion years was estimated at greater than 90% of the net summer lake change for Na, and SO_4, and at 50% for Cl. Note that these are very rough approximations, and much additional work is needed to integrate groundwater chemistry and inflow data with surface water data. Regardless, groundwater influx could account for a significant fraction of the major ions in the lake.

Runoff also contributes to total input of these ions. The total pump house load (1997 through 2002) for Na, SO_4, and Cl was about 45%, 75%, and 55%, respectively, of the corresponding load at Mirror. This suggests that a significant fraction of the load for these ions could be delivered via watershed runoff. For 1997 through 2002, the approximate average loads of Na, SO_4, and Cl through Parlby Creek at Mirror were about 5%, 20%, and 30%, respectively, of the net summer lake change. Similarly, respective overall surface water contributions of these ions were estimated at about 10%, 25% and 55%. Therefore, surface water may contribute a relatively small load of Na to the lake, compared to groundwater, whereas for other ions, such as Cl, a more substantial fraction of the annual load to the lake comes from surface runoff.

In addition to net transport from Parlby Creek input, wind-induced mixing may produce some movement between bays (Norecol Env. Cons, 1984). Consequently, circulation and movement of water between basins could also account for local loss and gain of ions and other constituents. TDS concentrations have historically been lower in Secondary Bay than in Main Bay, suggesting that mixing between the major bays may be limited. However, there was a loss of TDS from Main Bay over the summer of 1999 (~1.5 Mkg), which may partially be accounted for by a concurrent increase in Secondary Bay (~2.5 Mkg).

Finally, evaporative water loss is a major process influencing the mass and balance of major ions in the lake. Since no discharge is known to occur, conservative ions entering the lake will likely remain in solution, subject to solubility constraints (e.g., carbonate precipitation). Evaporation is significant in the annual lake water balance (e.g., for 1997, evaporative loss was estimated at about 1.8 times the runoff inflow volume; Douglas, 1998) and has effectively increased the concentrations of dissolved constituents over time. In most natural waters undergoing evaporation, calcite ($CaCO_3$) is the first mineral to precipitate. Calcium removal is apparent in post-diversion lake data as a decrease in concentration from Parlby Bay to Main Bay (see above), and as a decrease in mass load relative to increases in the mass of other more conservative ions, such as sodium (Figure B2 (e), Appendix B). These processes likely account for the fact that although most inflows to Buffalo Lake are of moderate TDS concentration with Ca and HCO_3 as principal ions, the lake itself is somewhat saline with Na, HCO_3, and SO_4 as principal ions.

Given the carbonate alkalinity concentration in the lake, it is likely that calcium precipitation will continue, and lake waters will increasingly tend towards an alkaline carbonate brine (Eugster and Hardie, 1978; summary in Drever, 1988). Along this path, Mg precipitation (e.g., as sepiolite and/or carbonate) constitutes the next "chemical divide", involving Mg^{2+}, HCO_3^-, and H_4SiO_4. Through the evaporative process, major ions such as Na^+, K^+, SO_4^{2-}, and Cl^- are likely to become progressively more concentrated (although SO_4^{2-} concentration may be subject to control by gypsum precipitation and/or sulphate reduction). Plots of sodium vs. other major ions (Figure B2 (a to i), Appendix B) illustrate the common control of major ions in Buffalo Lake by evaporation (with the exception of Ca^{2+}).

3.3 Nutrients

Phosphorus and nitrogen are primary nutrients governing the growth of algae and other aquatic plants in most lakes. They were measured in all samples collected during Parlby Creek-Buffalo Lake water quality studies from 1995 through 2002. In most freshwater lakes, phosphorus concentration provides a good indicator of water quality, because phosphorus is typically the nutrient in shortest supply relative to the requirements for algal growth. If an abundant phosphorus supply exists, substantial growth (i.e., mass) of algae may occur in the lake, resulting in reduced recreational water quality.

Despite relatively high phosphorus concentrations, nuisance algal growth has not occurred in Buffalo Lake in the past. This is probably due to relatively high lake salinity, which may act to suppress the growth of salt-intolerant algal species (Goudey et al., 1990; Bierhuizen and Prepas 1985), and limit the bioavailability of phosphorus (Waiser and Robarts, 1995) and iron (Evans

and Prepas, 1997). Nitrogen (as nitrate or ammonia) is also an essential nutrient, but in Alberta lakes, nitrogen does not generally control the size of the algal population.

3.3.1 Diversion Route and Parlby Creek

Average nutrient data for the Red Deer River and sites along the diversion route are presented in Table 5. In 1997 and 1998, phosphorus concentrations in the Red Deer River diversion were lower than in Buffalo Lake, and these concentrations declined even further in the diversion channel between the river and Alix Lake. Phosphorus was removed from the water in the early part of the season while nitrogen, primarily organic nitrogen, was added. This can be explained by the growth of aquatic plants along this section, which convert inorganic nitrogen and phosphorus to organic compounds. By the end of the pumping season, nutrient concentrations in river water and at Alix Lake Inflow were similar (Mitchell, 1999).

Data collected in 1997 and 1998 showed that Alix Lake water quality had improved considerably over pre-diversion years, and that Alix Lake water quality was similar to that of the Red Deer River. Detailed analysis of diversion water quality can be found in a previous report (Mitchell, 1999). The data from subsequent years (1999-2002) show no obvious trends between Red Deer River and Alix Lake nutrient values; however, nutrient concentrations in Alix Lake have remained relatively constant since the diversion began (Figure B3; Appendix B). As noted above, the 2002 sample collected from Parlby Creek at Mirror (May 29; Appendix A) reflects spring water quality in Parlby Creek during the commencement of pumping, and is similar to spring water quality samples collected in prior years at that site (e.g., Mitchell, 1999). These samples typically display elevated nutrient concentrations (influenced by run-off), relative to samples collected during active diversion periods.

The estimated mass load of total phosphorus from the Red Deer River at the pump house through the summers of 1997 through 2002 was less than or equal to about 4% of the total phosphorus mass in Main Bay (Figure 6). The measured annual diversion phosphorus mass was generally similar to the 475 kg used by Goudey et al. (1990) for pre-project impact predictions (Table B3; Appendix B). Mitchell (1999) noted that the mass of total phosphorus at the Mirror site on Parlby Creek for 1997 - 1998 was only slightly higher than the mass in the river diversion, although natural runoff in the Parlby Creek watershed was estimated to have contributed phosphorus mass equivalent to the amount in the diversion. Still, nutrient loading from local runoff is apparent as higher phosphorus and nitrogen concentrations at Mirror relative to Alix Lake values. Goudey et al. (1990) predicted that there would be uptake of phosphorus along the diversion route (particularly at Spotted Lake), and as a result not all of the diverted mass load would reach Buffalo Lake. This was notably apparent in the 1998 data, although the diversion does represent an increased phosphorus load to Buffalo Lake compared with the pre-diversion natural load. Data is not available at the Mirror site for 1999 through 2002. However, data for these years does show some uptake/loss of total phosphorus through the diversion from the pump house site to the Alix Lake (control structure) site (Figure 6, Table B3; Appendix B). Note that

Table 5 Annual average concentrations of nutrients and bacteria for the Red Deer River and Buffalo Lake Diversion during the diversion period (June through October) 1997-2002

	Red Deer River at Pumphouse			Red Deer River @ Nevis			
	1996	1997	1998	1999	2000	2001	2002
Total Phosphorus	33	33	65	59	57	87	11
Total Dissolved Phosphorus	13	9	9	19	20	8	7
Total Nitrogen	347	419	523	503	597	504	256
Nitrite + Nitrate - N	84	79	40	35	57	48	21
Ammonia - N	20	10	39	11	11	25	7
Total Kjeldahl Nitrogen	333	340	483	508	569	458	250
Chlorophyll *a*	--	--	--	2	3	8	1
Secchi Depth	--	--	--	--	--	--	--
Fecal Colif. Bacteria, cts/100 ml	21	15	36	23	16	23	10
E. coli, cts/100 ml	19	9	28	13	6	9	10

	Alix Lake							Parlby Creek at Mirror		
	1996	1997	1998	1999	2000	2001	2002	1996	1997	1998
Total Phosphorus	31	20	28	27	21	29	22	72	65	59
Total Dissolved Phosphorus	10	8	8	9	8	9	8	45	39	43
Total Nitrogen	646	433	739	620	506	488	509	752	566	786
Nitrite + Nitrate - N	2	3	3	2	2	8	3	17	6	2
Ammonia - N	65	13	14	13	14	6	17	53	19	16
Total Kjeldahl Nitrogen	644	450	736	618	504	480	507	749	560	784
Chlorophyll *a*	8	4	6	6	5	8	5	--	--	--
Secchi Depth	2.0	2.7	2.6	2.6	2.7	2.2	3.0	--	--	--
Fecal Colif. Bacteria, cts/100 ml	--	--	--	--	--	--	--	67	25	33
E. coli, cts/100 ml	--	--	--	--	--	--	--	60	19	22

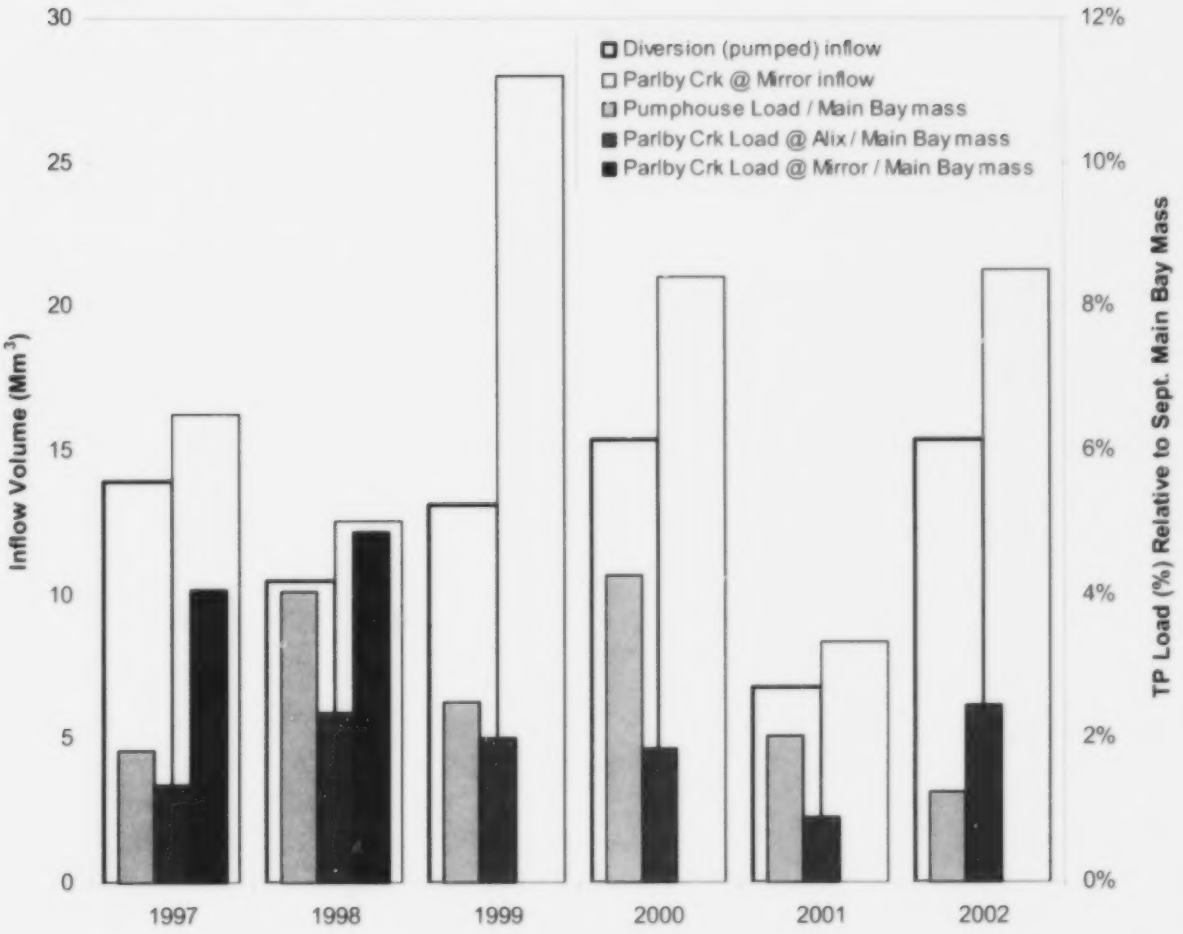


Figure 6 Diversion loads of total phosphorus to Buffalo Lake: 1997 – 2002

the pumped TP load varies considerably (relative to volume), due to changes in Red Deer River water quality that are influenced by point sources and by variable runoff loads (e.g., wet years vs. dry years). Despite this variability, phosphorus loading from the diversion is a relatively minor portion of the annual total phosphorus load to Buffalo Lake, especially in years of high natural inflow.

3.3.2 Parlby Bay

Average nutrient concentrations in Buffalo Lake for 1997 through 2002 are listed in Table 6. These concentrations have not changed considerably over the past few years, though there are slight differences in Parlby and Secondary Bays. Average total (TP) and dissolved (TDP) phosphorus concentrations in Parlby Bay decreased subsequent to diversion start-up, as might be expected with the increased flushing rate resulting from the diversion. However, TP and TDP

Table 6 **Annual average concentrations of nutrients and chlorophyll *a* (mg/m^3) and Secchi depth (m) for Buffalo Lake, June-October 1995 (pre-diversion), through 2002**

Number of samples = 3 to 6 for each area per year.

	Parlby Bay							Secondary Bay						
	95	97	98	99	00	01	02	95	97	98	99	00	01	02
Total Phosphorus	73	52	61	81	83	54	35	80	105	97	83	77	77	59
Total Dissolved Phosphorus	30	26	25	42	40	23	16	30	34	38	32	28	33	23
Total Nitrogen	1732	1100	1136	1201	981	948	562	3026	3492	2106	1642	1731	2033	1882
Total Kjeldahl Nitrogen	1729	919	1130	1196	978	940	560	3024	3476	2088	1630	1728	2023	1863
Nitrite + Nitrate - N	3	2	6	5	3	8	2	2	16	18	12	2	10	20
Ammonia - N	29	30	28	24	38	39	7	25	73	66	68	50	50	71
Chlorophyll *a*	9.1	3.9	5.9	12.1	16.8	6.2	4.1	8.1	19.4	14.9	12.8	11.7	10.4	6.3
Secchi Depth	bot	0.7	bot	0.9	0.8	1.0	0.7	1.2	0.7	0.7	0.8	1.4	1.2	1.4
TP/TDP	2.4	2.0	2.4	1.9	2.1	2.3	2.2	2.7	3.1	2.6	2.6	2.7	2.4	2.6
TP/TN	0.04	0.05	0.05	0.07	0.08	0.06	0.06	0.03	0.03	0.05	0.05	0.04	0.04	0.03

	Main Bay						
	95	97	98	99	00	01	02
Total Phosphorus	67	80	68	67	61	62	57
Total Dissolved Phosphorus	36	38	36	34	34	34	32
Total Nitrogen	2798	2747	2213	2251	1730	2161	2267
Total Kjeldahl Nitrogen	2789	2727	2200	2224	1714	2148	2258
Nitrite + Nitrate - N	9	20	13	27	16	14	9
Ammonia - N	32	51	55	52	58	37	73
Chlorophyll *a*	9.4	12.9	12.7	14.3	7.4	14.6	6.9
Secchi Depth	1.9	1.7	1.9	1.8	2.4	2.5	2.2
TP/TDP	1.9	2.1	1.9	2.0	1.8	1.8	1.8
TP/TN	0.02	0.03	0.03	0.03	0.03	0.03	0.03

Note: shade indicates pre-diversion

concentrations increased in 1999 - 2000, coincident with substantially increased inflow and phosphorus mass (Table B1, B2; Appendix B).

In subsequent years, phosphorus concentrations and mass have generally declined. As well, TP concentrations declined through the summer season in 1997, 1998, 2001, and 2002, although a contrasting summer increase occurred during 1999 and 2000, the years of highest local runoff (Figure B3; Appendix B). Annual trends in average total nitrogen and Kjeldahl nitrogen (TKN) concentrations were similar to phosphorus data. However, ammonia concentrations were low in 1999, relative to other years. This was also evident in ammonia mass, most notably in spring values (Appendix B).

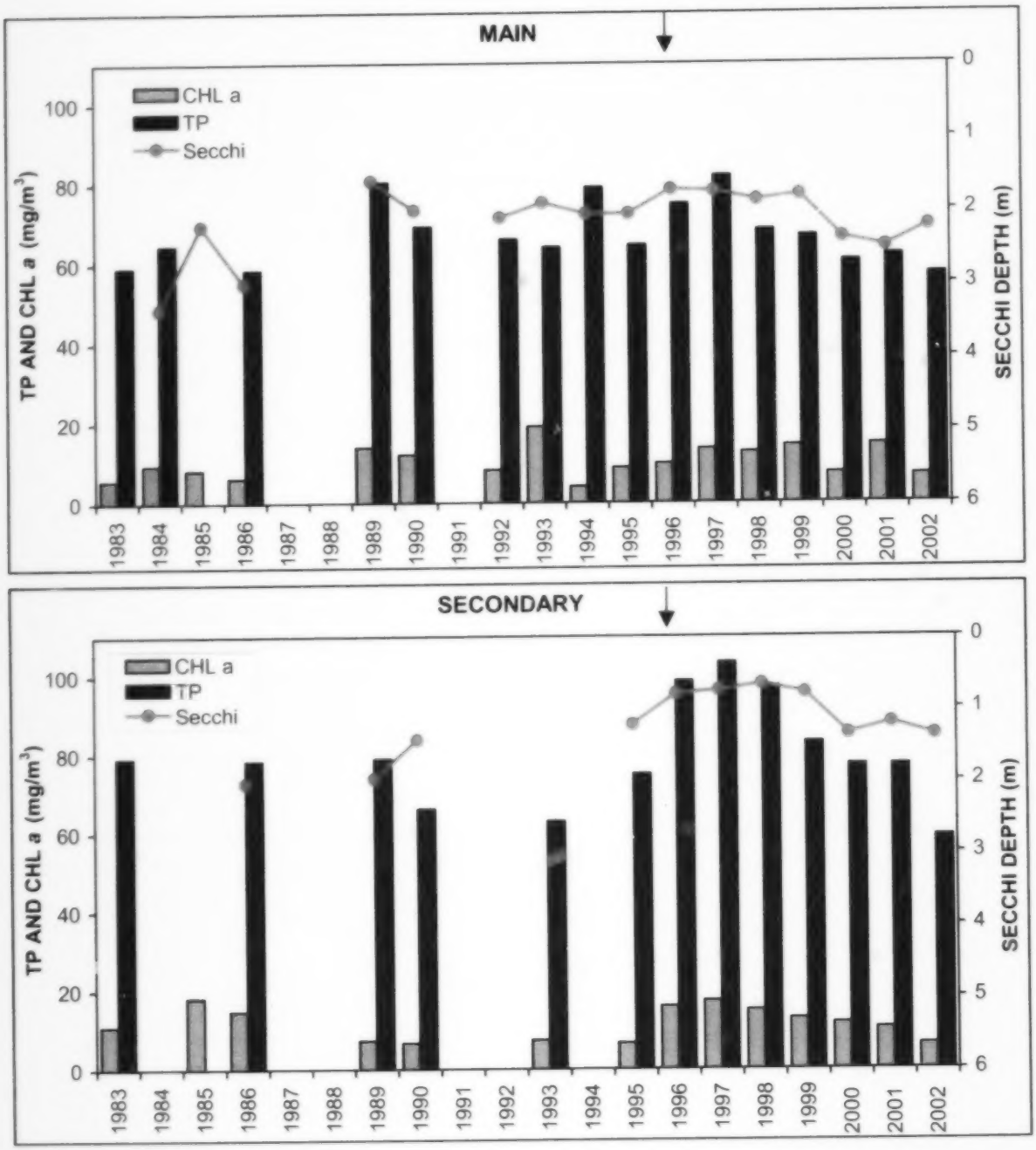
3.3.3 Secondary Bay

The average total phosphorus concentration in Secondary Bay was higher in the initial three diversion years than was observed in previous years sampled; however, subsequent values fell generally within the historical range (Figure 7). Although the concentrations of total phosphorus (TP) were variable from year to year, the amount of TP relative to dissolved phosphorus (TDP) remained relatively constant, ranging from 2.4 to 2.7 in 1999 to 2002 (Table 6). September TP mass remained relatively constant subsequent to 1997, with a low of 3800 kg in 2002 (Table B1; Appendix B).

In post-diversion years, TP concentrations generally increased in Secondary Bay through the summer season (Figure B3; Appendix B). This increase suggests that bottom sediments may be an intermittent source of phosphorus for Secondary Bay. To illustrate, approximately 60% of the 3300 kg increase in phosphorus mass in the bay from June to September 1997 was unaccounted for by estimated watershed, Parlby Bay, and atmospheric inputs. This internal load of phosphorus was likely larger to some degree, as a fraction of the phosphorus mass would have migrated into Main Bay. A rough estimate for this transport is 1400 kg for the June to September period, indicating an internal load to Secondary Bay of about 3400 kg (Table B4; Appendix B). In the years following 1997, the estimated internal load for June to September was smaller, ranging from near zero in 1999 to about 2600 kg in 2001. This may explain, in part, why phosphorus concentrations in Secondary Bay have generally been lower following 1997. However, the nature of phosphorus movement between basins is not well known.

As noted above, phosphorus concentrations fluctuated somewhat from 1999 through 2002, although have remained at historic (pre-diversion) levels (Figure 7). Additional years of sampling will be needed to determine whether present phosphorus concentrations in Secondary Bay represent a new balance with respect to inputs, and to what degree inflows and nutrient transport affect phosphorus concentrations.

The average total nitrogen concentration in Secondary Bay was higher in 1997 than in subsequent years, which ranged from 1640 mg/m^3 in 1999 to 2110 mg/m^3 in 1998. Values for the last three years (2000 - 2002) fall within a relatively narrow range, from 1730 to 2030 mg/m^3 (Table 6). Inorganic nitrogen concentrations have remained variable in the post-diversion years, though increased somewhat over the last three years.



Note: Arrow indicates diversion start-up

Figure 7 Average open-water Secchi depth and concentrations of chlorophyll *a* and total phosphorus in Buffalo Lake, May-September

3.3.4 *Main Bay*

As with Secondary Bay, the average total phosphorus concentration in Main Bay was higher in the initial three diversion years than in subsequent years sampled. However, annual differences in average phosphorus and nitrogen concentrations through all post-diversion years fell within the historical range (Table 6). A comparison of average phosphorus concentrations for the diversion years with those from previous years sampled also suggests no overall change (Figure 7).

In general, concentrations of total phosphorus increased through the summer in most years (Figure B3, Appendix B), but declined over the summer of 1998 and remained relatively constant through the 2002 season. This increase in summer phosphorus cannot be explained solely by inputs from the watershed, Secondary Bay and atmospheric deposition, although summer P release from sediments is common in many Alberta lakes. To illustrate, amount of phosphorus mass in Main Bay during 1997 increased by 7300 kg between June and the end of September (Table B2, Appendix B). External inputs amounted to about 3800 kg, of which about 1400 kg was estimated to come from Secondary Bay (assuming that water moved into Main Bay from Secondary Bay at rate equal to Parlby Creek at Mirror). The 3500 kg that remains unaccounted for may have come from the lake bottom. This internal load would include phosphorus contributed by groundwater and sewage, although the latter is probably minimal. Summer (June to Sept.) internal loading was also evident in 2001 (2050 kg). However, this was not apparent in 1998, 1999, 2000, and 2002, suggesting that internal phosphorus loading occurs intermittently[4]. Eventually, internal loading may reach a new steady state, as occurred in sediment experiments conducted on Eagle Lake near Calgary (Environmental Management Associates 1991).

September mass loads of phosphorus and nitrogen for 1996 through 2002 are presented in Table B1 (Appendix B). In general, annual differences in phosphorus mass within each major basin in the post-diversion years are fairly minor, despite the suggestion of trends by concentration data. Interestingly, during 2002 in Main Bay, when annual precipitation was at long-term low relative to previous years (Figure 2), total phosphorus was lower and ammonia mass was higher than in the preceding years 1995 - 2001.

In all three basins, the mass of nitrite+nitrate nitrogen (NO_2+NO_3) declined dramatically in 1998, and generally remained lower in subsequent years, increasing to near-1996 values in 2002. In Main Bay, a substantial increase in mass was apparent in 1999. Total Kjeldahl nitrogen displayed similar trends. Overall trends were not evident for ammonia-nitrogen (NH_3) mass though NH_3 displayed some similar changes to those of other nitrogen species, such as a post-1997 decline in Secondary Bay.

3.3.5 *Buffalo Lake Phosphorus Budget*

Apparent changes in total phosphorus mass within each lake basin are probably influenced by a number of factors, such as inflow and flushing rates through Parlby and Secondary Bays, driven

4 Note that internal load components represent rough estimates that are calculated by difference. Hence, depending on the calculated estimates for other components, internal loads can appear to be negative.

by spring and summer runoff volumes. This may explain, for example, the lower phosphorus mass in Secondary and Main Bay in 2002 relative to previous years, and the increase in Parlby Bay phosphorus in 1999. Also, other processes within the lake, such as advection and nutrient cycling, may produce some delay or attenuation of changes in concentration or mass due to nutrient loading.

With the above factors in mind, a theoretical phosphorus "budget" for Buffalo Lake is presented in Appendix B (Table B4; Figure B5 (a & b)). Note that the estimates for net internal load represent very rough calculations, though do provide an indication of the potential difference in phosphorus loading that can occur from year to year. It is likely that some variability in loading calculations is due to uncertainty in mass calculations (e.g., measurement error, uncertainty in annual watershed inputs, sample timing and frequency, etc.), and to variable loading from groundwater flux. As noted in Section 3.2.2, fluctuating lake levels could influence groundwater influx.

Nutrient loads from the diversion did not seem to significantly influence nutrient concentrations in Main Bay. Overall, the average annual TP mass from the river diversion was less than 3% of the estimated TP mass in Main Bay, and the diversion contributed a minor portion (an average of about 4%) of the TP load to Buffalo Lake in a given year. Moreover, water from the diversion (mixed with natural runoff) passes first through Parlby and Secondary bays before entering Main Bay. Hence, constituent concentrations are attenuated by dilution, uptake, and loss. For example, from 1997 to 2002, the average estimated phosphorus loading from Secondary Bay to Main Bay (assuming the same flow rate as the diversion) was about 1200 kg during June – September. This contribution increased the total phosphorus concentration in Main Bay by about 5 mg/m^3, an amount within measurement error and natural variation in the bay.

The average amount of phosphorus contributed by the watershed overshadows the diversion contribution, and is about 60% of the total load. There is significant variability in this estimate, which is highest in years of high annual inflow (i.e., wet years). As expected, total annual watershed TP load is strongly correlated with total annual inflow ($r^2 = 0.9$).

Internal loading estimates are also important, though quite variable, being substantial in some years and negative (i.e., representing a net loss of phosphorus) in others. Relative to total annual TP input, the largest estimated internal load in the years following 1997 occurred in 2001, the year of lowest annual inflow. Similarly, the lowest relative internal load was apparent in 1999, the year of highest annual inflow.

3.4 Chlorophyll *a*

Chlorophyll *a* (chl *a*) is a photosynthetic pigment in algal cells, and provides an estimate of the amount of suspended algae (biomass) in the lake at the time of sampling. Along with phosphorus levels, chl *a* concentration indicates the productivity (amount of algal growth) or trophic status of a lake and is good indicator of recreational water quality.

In post-diversion years, Alix Lake has been completely flushed by diversion water that is relatively low in nutrients. Consequently, the average amount of chl *a* in lake water has also

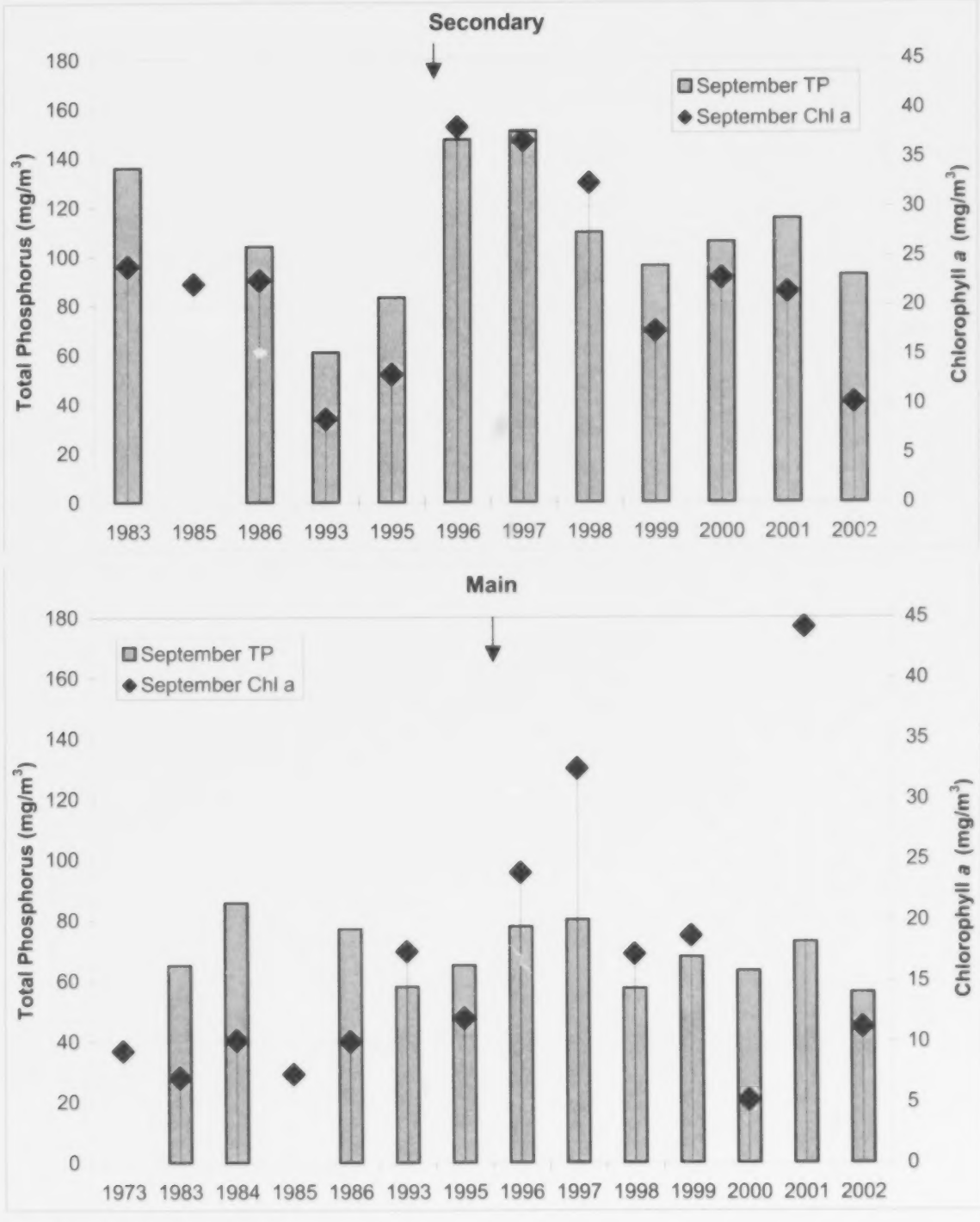
decreased (see text box below). Concentrations of chl *a* have remained at moderate levels through the summer seasons (Figure B4; Appendix B). Thus, in terms of the amount of suspended algae in the water, the diversion has had a positive effect on the recreational water quality of Alix Lake.

Average Concentrations of Chlorophyll *a* in Alix Lake, May-October, 1992-2002 (mg/m^3)

1992	16.1	– Eutrophic (high productivity; 8-25)
1996	7.8	
1997	4.0	
1998	5.9	
1999	6.2	– Meso-eutrophic (moderate productivity; 2.5-8)
2000	4.5	
2001	8.0	
2002	4.2	

As in Alix Lake, Parlby Bay is also flushed through the open water season with water containing relatively low levels of nutrients. Consequently, mean annual chl *a* concentrations in Parlby Bay have declined (Table 6) with the exception of 1999 – 2000, when higher concentrations were apparent, coincident with increased phosphorus concentrations. Chl *a* levels declined through the summer in 1997 and 1998 as phosphorus concentrations decreased, and increased with summer phosphorus levels in 1999 and 2000. Chl *a* increased through the summer in 2001 and 2002, in contrast with minor decreases in phosphorus (Figure B3; Appendix B). The average chl *a* concentration in post-diversion years places Parlby Bay in the mesotrophic category, (2.5 – 8 mg/m^3), with the exception of 1999 and 2000; in these years the bay was eutrophic (8 – 25 mg/m^3). This rating is based on phytoplanktonic chl *a*, which does not consider macrophyte populations in the bay.

For Secondary Bay, annual average post-diversion chl *a* concentrations fell within the historical range (Figure 7). Median annual average chl *a* in the years from 1999 through 2002 was not significantly higher than the corresponding value for pre-diversion years from 1983 through 1995 (Wilcoxon Mann-Whitney Test). However, annual chl *a* values displayed a steady decline from 1997 through 2002. September chl *a* measurements were higher in the initial post-diversion years (1996 and 1997, and to some extent 1998) than in previous years (Figure 8). This may be a result of internal phosphorus loading to the bay, or could be related to the decreased salinity and higher TP concentrations measured during 1996 and 1997. Earlier studies predicted that Secondary Bay would have higher algal biomass under project conditions (Alberta Environment 1984; Goudey et al., 1990). However, chl *a* concentrations declined in the years



Note: Arrow indicates diversion start-up

Figure 8 Historic September concentrations of chlorophyll *a* and total phosphorus in Secondary and Main Bays

following 1998, possibly due to a general decrease in phosphorus within the bay (concurrent with reduced watershed runoff), or to a general increase in salinity following 1999.

Observed changes in chl *a* cannot be explained solely by changes in salinity. Post-diversion increases in salinity have not typically produced a concomitant decrease in chl *a* levels in Secondary Bay (e.g., 1998, 2001). Historically, there is no consistent relationship between conductivity (a measure of salinity) and chl *a* concentrations in the bay. Overall, algal growth (as chl *a*) appears to respond more to phosphorus concentration than to salinity, as Noton (1984) suggested. To illustrate, September data from Secondary Bay for 1983 to 2003 show a significant relationship between chl *a* and total phosphorus ($r^2 = 0.8$); however, no such relationship is evident with conductivity.

In Main Bay, post-diversion values fell generally within the historic range (Figure 7). The median annual chl *a* in the years from 1999 through 2002 was not significantly different than the corresponding value for pre-diversion years from 1983 through 1995, and no clear trend was evident in post-diversion annual chl a values. September chl *a* concentrations were high in 1996 and 1997 relative to previous years, although in later years were also generally in the historic range. Note that the 2001 value is anomalously high and may represent a measurement artefact (Figure 8).

As noted by Mitchell (1999), peak chlorophyll *a* concentrations in Main Bay have historically occurred in August most years, whereas in 1997 and 1998, the chl *a* peak appeared in September. In these years, phosphorus concentrations also appeared to peak somewhat later in the summer. Mitchell hypothesized that the diversion inflow may have enhanced the movement of phosphorus from Secondary Bay into Main Bay, where formerly there was very little inflow to Main Bay during the latter part of the summer. This may have allowed algal populations to persist later into the summer.

Data from subsequent years suggest that the chl *a* peak in Main Bay occurred in August during 1999 and 2000, and in September during 2001 and 2002 (Figure B4, Appendix B). This was similar to the timing of peak phosphorus concentrations, although no summer maximum is apparent in the 2002 phosphorus data. The early (August) peaks in 1999 and 2000 chl *a* may be due to the high natural inflows that occurred in those years, compared with diversion inflows (Figure 3). Hence, in years of low watershed inflow relative to diversion flow, recent data supports the concept of enhanced late summer movement of phosphorus into Main Bay due to diversion inflow. Nonetheless, other natural influences, such as seasonal weather patterns, may also influence the timing of seasonal algal abundance.

3.5 Dissolved Oxygen

Buffalo Lake is well mixed during the summer, and during this time dissolved oxygen concentrations typically remain high. In winter, dissolved oxygen can decrease dramatically, particularly in shallow areas and in bottom waters of the main lake. For example, in March of 1997, near-zero dissolved oxygen (DO) concentrations were measured in Parlby Bay and Secondary Bay, while concentrations in Main Bay bottom waters were ≤ 2 mg/L (this is typical of historic data from other winters). Historically, near-anoxic conditions occurred during some

winters in Secondary Bay, but in others, DO levels have remained high (e.g., 2000). There are insufficient historical data for Alix Lake and Parlby Bay to assess past conditions, but it is likely that these shallow water bodies become anoxic in winter as well. In Main Bay, DO levels are generally sufficient to allow fish survival in the top three or four metres (2 to 6 mg/L). Temperature and dissolved oxygen profiles for Main Bay during 2000 are shown in Figure 9. Assessment of lake profile data for other years shows no consistent inter-annual trends; e.g., between pre- and post-diversion years.

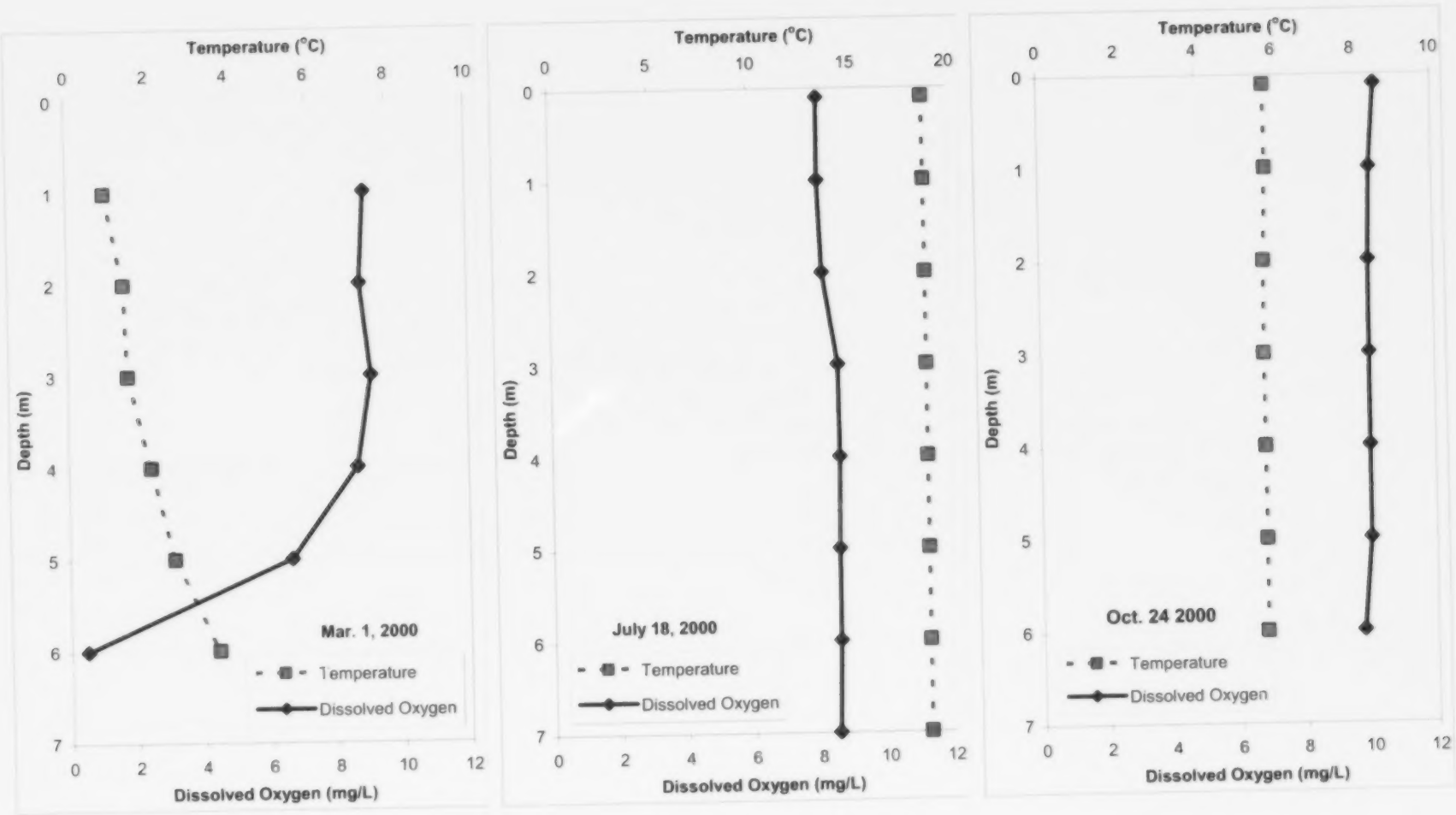


Figure 9 Temperature and dissolved oxygen profiles from Buffalo Lake, Main Bay, 2000

4.0 CONCLUSIONS

- Although comparative pre-diversion data are limited, it appears the diversion has had a positive effect on recreational water quality of Alix Lake. Data collected in 1992 indicate that the lake was eutrophic, yet in post-diversion years the lake has generally remained mesotrophic, and water quality of the lake closely resembles that of Red Deer River water. Some uptake and loss of nutrients (e.g., phosphorus) does occur through the diversion route to Alix Lake, as well as the addition of major ions such as Na, SO_4, and Cl. Provided that water quality in the Red Deer River is maintained, the diversion is a benefit to Alix Lake. However, if nutrient levels should gradually increase in the Red Deer River, users of Alix Lake might perceive deterioration in its water quality. This may be especially so with the rapid flushing the lake would receive under a full pumping program.

- The salinity of Buffalo Lake has generally increased over the long term, and for a given lake level, conductivity is higher post-diversion than in pre-diversion years. This suggests that the mass load of major ions in the lake has increased since the diversion has been operational, though post-diversion conductivity in both bays is within the historical range. General trends in conductivity are similar between Main and Secondary Bays, although Secondary Bay displays more variability. Annual differences are attenuated in Main Bay, as would be expected with the small inflow volume relative to the volume of the bay. Hence, in any given year, lake level and inflow volume probably exert a greater influence on salinity in Secondary Bay than in the larger Main Bay.

- Diversion water is generally dilute relative to lake waters, yet provides an overall increase in ion mass loading to Buffalo Lake. Groundwater influx may play a significant role here (e.g., sodium input), and further evaluation of groundwater chemistry and influx estimates would aid in determining the specific nature of groundwater influence on lake chemistry

- Evaporation is a significant process and has the net effect of increasing the concentrations of dissolved constituents over time. Under current conditions with no significant discharge from the lake, it is likely that the concentrations of major ions will increase, producing a continuing trend towards higher salinity.

- Average total phosphorus concentrations in Secondary and Main Bay were higher in the initial diversion years than in previous years sampled. Subsequent values fell generally within the historical range, as did chl *a* values, though mean annual chl *a* displayed a steady decline in Secondary Bay from 1997 through 2002. Post-diversion increases in salinity have not typically produced a concomitant decrease in chl *a* concentrations Overall, algal growth (as chl *a*) appears to respond more to phosphorus concentration than to salinity.

- Nutrient loading from the diversion has not measurably affected water quality in Main Bay. Because the diversion inflow volume was apparently small compared

with the volume in the lake, it contributed only a minor portion of the TP load to Buffalo Lake. The amount of phosphorus contributed by the watershed and internal loading constitutes the majority of the phosphorus input to the lake, and overshadows the diversion contribution.

- Given the variability in theoretical phosphorus loads to Buffalo Lake and the relative imprecision in these estimates, detailed areal estimates of phosphorus mass transported via surface runoff, along with further evaluation of groundwater chemistry and influx would aid in evaluating more precisely the primary phosphorus sources to the lake. Also, additional data should be collected from diversion sites, including Parlby at Creek at Mirror, to more clearly identify diversion impacts relative to natural variation influenced by climatic differences from year to year.

5.0 REFERENCES

Alberta Environment. 1984. Buffalo Lake regulation. Phase III studies: water quality, main report. Planning Division, Edmonton.

Alberta Environment. 2002. Water Quality Sampling Methods. Water Monitoring Group Compliance Branch, Northern and Southern Regions, Regional Services.

Anderson, A.-M. 1996. An analysis of non-compliance patterns to prairie provinces water board objectives in the Red Deer River at the Alberta/Saskatchewan boundary. Surface Water Assessment Br., Alberta Environmental Protection.

Bierhuizen, J.F.H. and E.E. Prepas. 1985. Relationship between nutrients, dominant ions, and phytoplankton standing crop in prairie saline lakes. Can. J. Fish. and Aq. Sciences, Vol.42, No. 10, pp. 1588-1594.

Brassard, B. and A. Trimbee. 1989. Water quality evaluation of Buffalo Lake stabilization project. Planning Division, Water Resources Management Service, Alberta Environment.

Carson-McCulloch Associates Ltd. and Golder Associates Ltd. 1997. Parlby Creek-Buffalo Lake water management project – mitigation report final edition. Prep. for Buffalo Lake Management Team, Red Deer.

Clare, Steve. 2004. Science and Standards Division, Alberta Environment; personal communication.

Crompton, F.M. 1984. Buffalo Lake mass balance study. Planning Division, Alberta Environment.

Douglas, Sean. 1998. Buffalo Lake Weekly Balance. Internal memorandum, Water Sciences Branch, Alberta Environment.

Drever, J.I. 1988. The Geochemistry of Natural Waters. Prentice Hall, 437 p.

Evans, J.C. and E.E. Prepas. 1997. Relative importance of iron and molybdenum in restricting phytoplankton biomass in high phosphorus saline lakes. Limnol. Oceanogr 42(3): 461-472.

Environment Canada. 1999. Canadian Environmental Quality Guidelines: Canadian Water Quality Guidelines. Environmental Quality Branch, Guidelines and Standards Division.

Environmental Management Associates. 1990. Parlby Creek - Buffalo Lake development project. Buffalo Lake stabilization component; Environmental Impact Assessment. Prepared for Planning Division, Alberta Environment.

Environmental Management Associates. 1991. Eagle Lake recreational project. Environmental Impact Assessment. Prep. for Aspen Ranches Ltd., Calgary.

Eugster, H.P. and L.A. Hardie. 1978. Saline Lakes. *In* Lakes – Chemistry, Geology, Physics, A. Lerman, ed. Springer - Verlag, New York, pp. 237-293.

Goudey, J.S., H.R. Hamilton, L.R. Linton, B. Taylor. 1990. Parlby Creek-Buffalo Lake development project, Buffalo Lake environmental impact assessment: Water Quality, HydroQual Canada Ltd., Calgary.

Mitchell, P. 1999. Water quality update 1997-98: Parlby Creek - Buffalo Lake water management project. Water Sciences Br., Alberta Env, Edmonton.

Mitchell, P. 1997. Water quality update 1996: Parlby Creek - Buffalo Lake water management project. Water Sciences Br., Alberta Env. Prot., Edmonton.

Mitchell, P. 1996. Water quality update 1995: Parlby Creek - Buffalo Lake water management project. Water Sciences Br., Alberta Env. Prot., Edmonton.

Mitchell, P. and E. Prepas (Eds.), 1990. Atlas of Alberta Lakes. University of Alberta Press, ISBN 0-88864-214-8.

Neis, Doug. 1998. Parkland Region, Alberta Environment, personal communication.

Norecol Environmental Consultants Ltd., 1984. Buffalo Lake water quality modelling study, Vol. 1. Prepared for Planning Division, Alberta Environment.

Noton, L.R. 1984. Buffalo Lake regulation. Potential effects on phytoplankton in Buffalo Lake, draft report. Planning Div., Alberta Environment, Edmonton.

Shaw, Jackie. 1994. 1993 Update: Water quality monitoring program for the Parlby Creek-Buffalo Lake water management project. Prep. for the Water Quality Subcommittee of the Buffalo Lake Management Team. Planning Division, Alberta Environmental Protection.

Shaw, R.D. and E. E. Prepas. 1990. Groundwater-lake interactions: II. Nearshore seepage patterns and the contribution of groundwater to lakes in central Alberta. J. Hydrol. 119:121-136.

Shaw, R.D, A.M. Trimbee, A. Minty, H. Fricker and E.E. Prepas. 1989. Atmospheric deposition of phosphorus and nitrogen in central Alberta with emphasis on Narrow Lake. Water, Air, and Soil Pollution 43:119-134.

Stumm, W., and J. Morgan, 1981. Aquatic Chemistry, 2nd. Ed. Wiley & Sons, New York. 780 p.

Waiser, M.J. and R.D. Robarts. 1995. Microbial nutrient limitation in prairie lakes with high sulphate concentrations. Limnol. Oceanogr 40: 566-574.

Walker, William W. Jr. 1996. Simplified procedures for eutrophication assessment and prediction: User manual. Instr. Report W-96-2, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss.

W-E-R Engineering Ltd. 1990. Buffalo Lake water balance analysis (1969 - 1988). Prep. for Env. Management Associates and Alberta Environment, Calgary.

Appendix A Water Quality Data for Buffalo Lake and Alix Lake: 1999 to 2002

Parlby Creek - Buffalo Lake Water Management Project - 1999 Water Quality Data

MAIN BAY - AB05CD1040

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
11-May-99	4.6	1.5	59.8	33.2	0.0015	0.02	2.05	3020	9.06	1770
08-Jun-99	3.8	3	57.6	37.2	0.075	0.09	2.50	2620	9.02	1730
20-Jul-99	6.5	1.4	76.1	38.6	0.0015	0.01	2.20	2610	9.04	1730
19-Aug-99	38.1	1.6	72.5	31.8	0.0015	0.05	2.02	2737	9.07	1673
14-Sep-99	18.7	1.5	67.9	29.6	0.057	0.09	2.35	2620	9.05	1660
average	**14.3**	**1.8**	**66.8**	**34.1**	**0.027**	**0.05**	**2.22**	**2721**	**9.05**	**1713**

SECONDARY BAY - AB05CD0860

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
11-May-99	12.3	0.6	95.8	27.4	0.0015	0.02	1.7	2240	8.9	1290
08-Jun-99	2.8	1.6	79.6	48.7	0.037	0.26	0.44	1820	8.78	1200
20-Jul-99	18.1	0.7	65.6	28.6	0.011	0.01	1.97	1730	8.89	1150
19-Aug-99	13.6	0.6	78.1	32.8	0.0015	0.02	1.94	1930	8.95	1180
14-Sep-99	17.4	0.4	96.0	24.9	0.007	0.03	2.1	1780	8.93	1210
average	**12.8**	**0.8**	**83.0**	**32.5**	**0.012**	**0.07**	**1.63**	**1900**	**8.89**	**1206**

PARLBY BAY - AB05CD0840

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
10-May-99	27.0	0.4	146.8	51.3	0.019	0.02	1.64	687	8.04	381
10-Jun-99	1.9	1	37.6	24.2	0.0015	0.03	0.45	444	8.56	275
13-Jul-99	1.8	1	42.5	29.5	0.0015	0.03	0.92	503	8.81	311
10-Aug-99	13.3	1	90.4	60.4	0.0015	0.01	1.81	631	8.38	381
08-Sep-99	16.6	1.1	87.6	43.0	0.0015	0.03	1.16	607	8.52	363
average	**12.1**	**0.9**	**81.0**	**41.7**	**0.005**	**0.02**	**1.20**	**574**	**8.46**	**342**

ALIX LAKE - AB05CD1070

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
10-May-99	12.3	2.2	39.7	11	*0.0015*	0.01	0.65	413	8.04	212
10-Jun-99	0.7	3.1	17.8	10.5	*0.0015*	0.02	0.61	355	8.06	204
13-Jul-99	3	2.5	21.5	5.6	*0.0015*	0.02	0.42	312	8.32	185
10-Aug-99	6.6	2.5	26.8	8.3	*0.0015*	*0.005*	0.73	334	8.22	193
08-Sep-99	8.3	2.8	27.6	8.6	*0.0015*	0.01	0.68	364	8.31	214
average	**6.2**	**2.6**	**26.7**	**8.8**	***0.0015***	**0.01**	**0.62**	**356**	**8.19**	**202**

Less than values = 0.5 of Detection Limit (in italics) *G=greater than*

Parlby Creek - Buffalo Lake Water Management Project - 1999 Water Quality Data

MAIN BAY - AB05CD1040

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L $CaCO_3$	Hardness mg/L
11-May-99	4.6	67.5	40.7	534	422	18.1	978	205	1140	290
08-Jun-99	5.6	74	41.2	536	358	17.2	1020	194	1160	320
20-Jul-99	6.2	71.8	38.9	495	430	16.9	977	191	1120	310
19-Aug-99	6.1	70.8	38.7	473	405	17.1	949	196	1103	303
14-Sep-99	5.2	66	36	490	368	17	958	200	1120	280
average	**5.5**	**70.0**	**39.1**	**506**	**397**	**17**	**976**	**197**	**1129**	**301**

SECONDARY BAY - AB05CD0860

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L $CaCO_3$	Hardness mg/L
11-May-99	9.4	50.3	29.7	381	300	14.3	755	127	831	230
08-Jun-99	17.3	53.5	26.2	326	287	12.8	765	97.3	789	260
20-Jul-99	14.1	50.7	26.2	314	296	13.9	676	100	721	240
19-Aug-99	13.9	53.2	27.7	322	284	12.4	704	118	773	250
14-Sep-99	16.2	55.8	29.2	332	293	14.8	691	126	776	270
average	**14.2**	**52.7**	**27.8**	**335**	**292**	**13.6**	**718**	**114**	**778**	**250**

PARLBY BAY - AB05CD0840

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L $CaCO_3$	Hardness mg/L
10-May-99	45.7	22	9.4	58.1	56.6	7.7	344	0.25	282	200
10-Jun-99	39.1	21.4	2.9	27.9	53.4	5.6	227	12.4	207	190
13-Jul-99	29.3	23.9	3.5	46	71.2	5.6	207	25.2	212	170
10-Aug-99	43.8	28.1	6.1	62.9	38.5	9.2	368	6.1	312	230
08-Sep-99	45.3	28.6	6.2	56.7	40.3	7.5	323	12.7	286	230
average	**41**	**25**	**6**	**50**	**52.0**	**7**	**294**	**11**	**260**	**204**

ALIX LAKE - AB05CD1070

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L $CaCO_3$	Hardness mg/L
10-May-99	37.6	17.6	4	14.4	31.1	4.6	205	*0.25*	168	170
10-Jun-99	35.3	17.7	2	12.9	35.9	4.2	195	*0.25*	160	160
13-Jul-99	28.5	15.9	1.9	11.9	39.1	4.8	160	2.1	135	140
10-Aug-99	24.5	20.1	3	19.1	41.4	4.8	159	*0.25*	130	140
08-Sep-99	31.8	20.6	2.5	20.9	33.9	8.8	182	1.8	152	160
average	**31.5**	**18.4**	**2.7**	**15.8**	**36.3**	**5.4**	**180**	**0.9**	**149**	**154**

Less than values = 0.5 of Detection Limit (in italics) *G=greater than*

Parlby Creek - Buffalo Lake Water Management Project - 2000 Water Quality Data

MAIN BAY - AB05CD1040

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
18-May-00	1.3	4.4	50	31	0.0015	0.08	1.34	2590	9.04	1780
26-Jun-00	4.4	1.8	61.5	34.9	0.0015	0.07	2.01	2447	8.96	1840
18-Jul-00	16.9	1.4	68.5	33.7	0.011	0.03	1.88	2630	8.94	1750
21-Aug-00	15	1.1	65	28.1	0.0015	0.03	1.62	2570	9.04	1740
20-Sep-00	5.2	1.9	63.3	32.4	0.073	0.06	1.72	2510	8.98	1840
24-Oct-00	1.7	3.7	55	41.3	0.005	0.08	1.72	2430	9.0	1880
average	**7.4**	**2.4**	**60.5**	**33.6**	**0.016**	**0.06**	**1.71**	**2529**	**8.99**	**1805**

SECONDARY BAY - AB05CD0860

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
18-May-00	1.3	2.2	59.4	31.4	0.0015	0.1	1.45	1980	8.88	1360
26-Jun-00	2.6	2	49.1	31.8	0.006	0.08	1.87	1950	8.88	1440
18-Jul-00	9.4	1.2	66.5	29	0.0015	0.04	1.86	2130	8.89	1340
21-Aug-00	16	0.7	93.5	26	0.0015	0.03	1.91	2070	9.0	1450
20-Sep-00	22.8	0.5	105.7	27.5	0.0015	0.02	1.42	1980	8.92	1420
24-Oct-00	18	1.5	89.7	23.2	0.0015	0.03	1.86	1800	8.91	1290
average	**11.7**	**1.4**	**77.3**	**28.2**	**0.002**	**0.05**	**1.73**	**1985**	**8.91**	**1383**

PARLBY BAY - AB05CD0840

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
26-May-00	2.2	1.1	64.8	50.5	0.0015	0.04	1.15	665	8.18	409
27-Jun-00	5.3	0.9	74.1	51.8	0.0015	0.02	1.04	660	8.37	385
20-Jul-00	9.2	1.1	92.4	53	0.0015	0.02	1.04	558	8.18	318
18-Aug-00	36.9	0.5	105.9	25.3	0.009	0.02	0.94	489	8.19	278
12-Sep-00	30.3	0.3	79	19.2	0.0015	0.09	0.72	411	8.28	244
average	**16.8**	**0.8**	**83.2**	**40.0**	**0.003**	**0.04**	**0.98**	**557**	**8.24**	**327**

ALIX LAKE - AB05CD1070

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
26-May-00	6.6	2.6	27.7	10.7	*0.0015*	0.02	0.8	364	8.1	215
27-Jun-00	3.4	2.6	20.8	7.6	*0.0015*	*0.005*	0.43	326	8.31	189
20-Jul-00	2.6	2.7	19.8	6.7	*0.0015*	0.02	0.44	332	7.79	184
18-Aug-00	4.8	2.5	22.4	7.4	*0.0015*	*0.005*	0.38	344	7.83	190
12-Sep-00	5.2	2.9	16.1	5.2	*0.0015*	0.02	0.47	323	8.14	199
average	**4.5**	**2.7**	**21.4**	**7.5**	**0.002**	**0.01**	**0.50**	**338**	**8.03**	**195**

Less than values = 0.5 of Detection Limit (in italics) *G=greater than*

Parlby Creek - Buffalo Lake Water Management Project - 2000 Water Quality Data

MAIN BAY - AB05CD1040

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
18-May-00	6.5	72.1	51.1	566	415	16.5	974	173	1090	310
26-Jun-00	6.8	75.6	42.5	600	457	16.1	958	167	1060	330
18-Jul-00	6.6	71.7	40.3	527	449	16.3	938	170	1050	310
21-Aug-00	6.9	72.8	42	549	404	17.8	922	195	1080	320
20-Sep-00	6.8	76.8	39.8	614	434	17.4	964	172	1080	330
24-Oct-00	10.1	80.5	44.8	597	486	17.9	967	167	1070	360
average	**7.3**	**74.9**	**43.4**	**576**	**441**	**17**	**954**	**174**	**1072**	**327**

SECONDARY BAY - AB05CD0860

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
18-May-00	12.7	58.1	39.9	430	315	13.8	772	111	818	270
26-Jun-00	13.3	63.4	33.9	488	320	13.9	788	122	849	290
18-Jul-00	13.2	59.8	31.8	375	342	13.6	758	133	843	280
21-Aug-00	13.7	60.9	33.8	479	317	15.8	762	153	880	290
20-Sep-00	9.1	64.8	29.7	467	326	15.9	775	124	843	290
24-Oct-00	17.9	62.4	34.1	360	311	13.9	741	116	801	300
average	**13.3**	**61.6**	**33.9**	**433**	**322**	**14.5**	**766**	**127**	**839**	**287**

PARLBY BAY - AB05CD0840

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
26-May-00	50.1	28.1	8.8	53.4	84.4	10.5	333	0.25	273	240
27-Jun-00	44.5	29.4	5.4	57.9	58.8	7.7	354	6.1	301	230
20-Jul-00	36.5	27.7	5.7	50.3	29.6	7.8	316	0.25	259	210
18-Aug-00	36.8	21.7	5.3	35.4	34.3	6.5	269	0.25	221	180
12-Sep-00	35.9	18.8	5.9	28.5	36.5	4.8	227	0.6	187	170
average	**41**	**25**	**6**	**45**	**48.7**	**7**	**300**	**1**	**248**	**206**

ALIX LAKE - AB05CD1070

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
26-May-00	34	17.4	3.6	19.7	35.7	6.9	194	*0.25*	159	160
27-Jun-00	22.7	19.2	2.9	20.3	41.5	3.9	152	2.8	129	140
20-Jul-00	26.6	17.4	2.2	15.7	34.3	5.6	166	*0.25*	136	140
18-Aug-00	35.6	16	2.5	11.8	34.6	3.3	172	*0.25*	141	150
12-Sep-00	32.5	15.5	5.9	20.6	35.8	3.9	172	*0.25*	141	140
average	**30**	**17.1**	**3.4**	**17.6**	**36.4**	**4.7**	**171**	**0.8**	**141**	**146**

Less than values = 0.5 of Detection Limit (in italics) *G=greater than*

Parlby Creek - Buffalo Lake Water Management Project - 2001 Water Quality Data

MAIN BAY - AB05CD1040

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
24-May-01	1.3	3.9	49.3	31.6	0.044	0.02	2.42	2430	8.85	
20-Jun-01	2.5	3.5	53.7	34.7	0.003	0.017	1.81	2497	9.07	1723
09-Aug-01	10.6	1.7	72.7	40.9	0.002	0.030	2.64	2630	9.20	1850
14-Sep-01	44.2	0.9	72.8	29.9	0.007	0.08	1.72	2470	9.23	1920
average	**14.6**	**2.5**	**62.1**	**34.3**	**0.014**	**0.037**	**2.15**	**2507**	**9.09**	**1831**

SECONDARY BAY - AB05CD0860

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
24-May-01	1.3	2.4	54.1	30.1	0.012	0.04	2.56	2190	8.8	
20-Jun-01	2.8	1.7	47.6	29	0.0015	0.04	1.92	2260	9.02	1540
09-Aug-01	16.1	0.4	92.3	29.9	0.016	0.04	1.97	2370	9.2	1680
14-Sep-01	21.4	0.3	115.2	41.7	0.012	0.08	1.64	2290	9.18	1740
average	**10.4**	**1.2**	**77.3**	**32.7**	**0.010**	**0.05**	**2.02**	**2278**	**9.05**	**1653**

PARLBY BAY - AB05CD0840

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
16-May-01	9	1	62.5	25.5	0.02	0.06	1.26	757	8.37	
21-Jun-01	2.1	1.1	63.1	33.0	0.0015	0.06	1.47	562	8.86	413
07-Aug-01	9.4		61.2	25.4	0.006	0.03	0.74	463	9.4	290
25-Sep-01	4.3	0.75	28.0	8.8	0.004	0.005	0.29	332	8.32	177
average	**6.2**	**1.0**	**53.7**	**23.2**	**0.008**	**0.04**	**0.94**	**529**	**8.74**	**293**

ALIX LAKE - AB05CD1070

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
16-May-01	12.3	2.6	34.2	8.1	0.019	*0.005*	0.65	340	8.00	
21-Jun-01	6.4	1.9	34	9.5	*0.0015*	*0.005*	0.76	250	8.35	176
07-Aug-01	7	1.6	30.9	11.8	*0.0015*	0.01	0.3	314	8.38	185
25-Sep-01	6.4	G2.8	18.5	4.8	0.009	*0.005*	0.21	349	8.22	183
average	**8.0**	**2.2**	**29.4**	**8.6**	**0.008**	**0.01**	**0.48**	**313**	**8.24**	**181**

Less than values = 0.5 of Detection Limit (in italics) *G=greater than*

Parlby Creek - Buffalo Lake Water Management Project - 2001 Water Quality Data

MAIN BAY - AB05CD1040

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
24-May-01	7.6	74.4	40.9	508	433	16.7	954	153	1040	330
20-Jun-01	6.7	76.7	44.1	510	439	17.1	916	177	1047	330
09-Aug-01	6.6	74.0	43.6	564	493	17.5	913	198	1080	320
14-Sep-01	6.3	78.1	45.5	638	465	17.8	912	220	1110	340
average	**6.8**	**75.8**	**43.5**	**555**	**458**	**17**	**924**	**187**	**1069**	**330**

SECONDARY BAY - AB05CD0860

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
24-May-01	11	69.9	36.5	456	374	16.1	887	117	921	320
20-Jun-01	10.8	70.3	38.5	452	383	16.4	848	148	941	320
09-Aug-01	10.5	70.4	41.3	506	441	16.9	836	177	980	320
14-Sep-01	9.9	73.3	41.1	563	406	18.8	871	192	1030	330
average	**10.6**	**71.0**	**39.4**	**494**	**401**	**17.1**	**861**	**159**	**968**	**323**

PARLBY BAY - AB05CD0840

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
16-May-01	35	26	10	110	87.1	7.4	398	6.4	337	190
21-Jun-01	29.1	28.7	6.9	84	73.1	8	291	39.2	304	190
07-Aug-01	17.4	27.5	4.3	58.6	40	6.8	151	57.6	219	160
25-Sep-01	25.2	18.8	1.6	16.8	39.3	3.7	143	0.8	118	140
average	**27**	**25**	**6**	**67**	**59.9**	**6**	**246**	**26**	**245**	**170**

ALIX LAKE - AB05CD1070

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
16-May-01	33	18	1.9	17	37.5	4.9	182	*0.25*	149	160
21-Jun-01	21.2	17.5	2.2	15.9	37.6	4	152	2.3	128	130
07-Aug-01	28.8	18.8	2.5	13.9	34.2	4.9	157	1.9	132	150
25-Sep-01	31.3	17.4	1.7	13.6	41.1	3.2	151	*0.25*	124	150
average	**28.6**	**17.9**	**2.1**	**15.1**	**37.6**	**4.3**	**161**	**1.2**	**133**	**148**

Less than values = 0.5 of Detection Limit (in italics) *G=greater than*

Parlby Creek - Buffalo Lake Water Management Project - 2002 Water Quality Data.

MAIN BAY - AB05CD1040

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	field COND uS/cm	10301 pH units	TDS mg/L
19-Jun-02	2.8	3.0	54.65	33.00	*0.0015*	0.12	2.38	2680	9.22	1930
15-Jul-02	5.6	1.9	62.60	31.17	*0.0015*	0.05	2.22	2827	9.24	1923
11-Sep-02	11.2	1.8	56.30	32.50	0.012	0.01	1.88	2580	9.28	1910
16-Oct-02	8.1		55.80	33.10	0.019	0.11	2.55	2970	9.25	2060
average	**6.9**	**2.2**	**57.3**	**32.44**	**0.009**	**0.07**	**2.26**	**2764**	**9.25**	**1956**

SECONDARY BAY - AB05CD0860

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
19-Jun-02	2.2	2.1	56.30	29.50	*0.0015*	0.07	1.98	2210	9.16	1580
15-Jul-02	4.5	1.1	60.40	27.60	0.009	0.18	1.13	2420	9.15	1570
11-Sep-02	10.2	0.9	92.25	27.90	0.017	*0.005*	2.08	2260	9.14	1520
16-Oct-02	8.2		27.60	5.20	0.052	0.03	2.26	2360	9.09	1590
average	**6.3**	**1.4**	**59.1**	**22.55**	**0.020**	**0.07**	**1.86**	**2313**	**9.13**	**1565**

PARLBY BAY - AB05CD0840

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
18-Jun-02	2	0.8	36.2	19.6	*0.0015*	*0.005*	0.74	415	8.5	238
17-Jul-02	6.1	0.7	42.0	16.5	*0.0015*	0.01	0.48	289	8.43	164
12-Sep-02		0.5	26.5	11.0	*0.0015*	*0.005*	0.46	275	8.6	163
average	**4.1**	**0.7**	**34.9**	**15.7**	**0.002**	**0.01**	**0.56**	**326**	**8.51**	**188**

ALIX LAKE - AB05CD1070

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
18-Jun-02	2.8	2.9	29.40	9.60	0.005	0.04	0.55	342	8.23	200
17-Jul-02	6.2	3.0	21.90	7.60	*0.0015*	*0.005*	0.69	318	8.87	181
12-Sep-02	3.6	--	15.80	6.10	*0.0015*	*0.005*	0.28	274	8.4	166
average	**4.2**	**3.0**	**22.4**	**7.8**	**0.003**	**0.02**	**0.51**	**311**	**8.50**	**182**

PARLBY CREEK AT MIRROR (gauging site) - AB05CD0440

Sampling Date	Chl *a* mg/m3	Secchi m	Total P mg/m3	TDP mg/m3	NO2+NO3 mg/L	NH3 mg/L	TKN mg/L	COND uS/cm	pH units	TDS mg/L
29-May-02	4.6	--	142.0	110.0	*0.0015*	0.09	1.18	712	8.31	457

Less than values = 0.5 of Det G=greater than

Parlby Creek - Buffalo Lake Water Management Project - 2002 Water Quality Data.

MAIN BAY - AB05CD1040

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
19-Jun-02	5.6	77	43.5	598	477	18.7	1045	186	1170	332
15-Jul-02	5.5	71.3	38.2	644	441	18.8	1017	203	1175	307
11-Sep-02	5.7	70.5	41.4	575	467	18.8	1030	221	1210	300
16-Oct-02	5.7	70.1	44.7	689	491	19	1040	223	1230	300
average	**5.6**	**72.2**	**41.9**	**627**	**469**	**19**	**1033**	**208**	**1196**	**310**

SECONDARY BAY - AB05CD0860

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
19-Jun-02	11.5	68.5	36.5	483	384	16.2	874	146	960	310
15-Jul-02	15	68.2	31.1	468	368	17.6	908	149	993	320
11-Sep-02	8.5	59.4	33.6	455	396	17	894	130	950	291.5
16-Oct-02	9	55.6	33	521	383	16	883	130	940	250
average	**11.0**	**62.9**	**33.6**	**482**	**383**	**16.7**	**890**	**139**	**961**	**293**

PARLBY BAY - AB05CD0840

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
18-Jun-02	29.5	20.4	2.4	28.9	48.5	6.9	192	6.2	167	160
17-Jul-02	26.6	14	1	13.3	35.5	3.6	130	3.7	113	120
12-Sep-02	26.6	15.5	1.6	10.3	38.4	2.8	127	5	112	130
average	**27.6**	**16.6**	**1.7**	**17.5**	**40.8**	**4.4**	**150**	**5**	**131**	**137**

ALIX LAKE - AB05CD1070

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
18-Jun-02	34.9	15.9	1.2	16.5	36.5	5.8	179		147	150
17-Jul-02	19	17.2	2.8	19.8	39.4	6	127	10.7	122	120
12-Sep-02	30.6	14.6	1.2	7.5	39.7	2.4	134	2.6	114	140
average	**28.2**	**15.9**	**1.7**	**14.6**	**38.5**	**4.7**	**147**	**6.7**	**128**	**137**

PARLBY CREEK AT MIRROR (gauging site) - AB05CD0440

Sampling Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO4 mg/L	Cl mg/L	HCO3 mg/L	CO3 mg/L	T. Alk. mg/L CaCO3	Hardness mg/L
29-May-02	59.1	31.5	7.8	60.1	112	11.3	333	5	281	280

Appendix B Concentrations and Mass Load Estimates for Water Quality Parameters in Buffalo Lake, Alix Lake and the Diversion: 1997 to 2002

Table B1. Estimated Substance Mass in Buffalo Lake, September 1996 - 2002

Major Ions and Related Variables

Site	Volume m3	Ca kg	Mg kg	K kg	Na kg	SO4 kg	Cl kg	HCO3- kg	CO_3^{2-} kg	TDS kg
Parlby Bay										
1996	539,829	17,760	12,524	2,057	12,632	20,406	1,781	107,966	21,809	123,621
1997	566,221	9,343	9,003	957	7,191	16,590	1,189	34,086	17,553	78,705
1998	559,448	11,748	9,119	2,685	9,267	12,588	1,119	72,169	9,678	92,309
1999	614,080	27,818	17,563	3,807	34,818	24,747	4,606	198,348	7,799	222,911
2000	616,656	22,138	11,593	3,638	17,575	22,508	2,960	139,981	370	150,464
2001	570,272	14,371	10,721	912	9,581	22,412	2,110	81,549	456	100,938
2002	545,702	14,516	8,458	873	5,621	20,955	1,528	69,304	2,729	88,949
Secondary Bay										
1996	40,260,459	805,209	2,741,737	1,433,272	17,030,174	18,600,332	579,751	35,308,422	4,026,046	55,277,610
1997	42,228,735	519,413	2,537,947	1,376,657	16,764,808	14,315,541	633,431	35,514,366	4,602,932	58,697,942
1998	41,723,627	367,168	2,762,104	1,531,257	18,400,120	15,187,400	600,820	36,549,898	5,382,348	62,168,205
1999	45,798,074	741,929	2,555,533	1,337,304	15,204,960	13,418,836	677,811	31,646,469	5,770,557	55,415,669
2000	45,990,237	823,225	2,869,791	1,568,267	16,556,485	14,302,964	639,264	34,078,766	5,702,789	65,306,137
2001	42,530,909	421,056	3,117,516	1,748,020	23,944,902	17,267,549	799,581	37,044,421	8,165,934	74,003,781
2002	40,698,452	366,286	2,262,834	1,343,049	21,203,893	15,587,507	651,175	35,936,733	5,290,799	61,861,647
Main Bay										
1996	229,114,293	1,262,420	19,658,006	11,157,866	143,883,776	112,724,232	4,101,146	239,882,664	46,281,087	438,066,527
1997	240,315,362	1,643,757	19,225,229	10,910,317	138,661,964	118,475,474	4,614,055	247,524,823	51,908,118	468,614,956
1998	237,440,895	1,139,716	19,303,945	10,637,352	131,542,256	112,072,102	3,965,263	236,491,131	49,862,588	444,014,474
1999	260,627,761	1,355,264	17,201,432	9,382,599	127,707,603	95,911,016	4,430,672	249,681,395	52,125,552	432,642,083
2000	261,721,325	2,643,385	21,068,567	11,725,115	156,247,631	127,196,564	4,684,812	253,084,522	45,016,068	481,567,239
2001	242,034,972	1,524,820	18,902,931	11,012,591	154,418,312	112,546,262	4,308,223	220,735,894	53,247,694	464,707,146
2002	231,606,824	1,320,159	16,235,638	10,352,825	159,577,101	113,718,950	4,400,530	240,871,097	51,185,108	442,369,033

Note: non-significant digits retained

Table B1. Estimated Substance Mass in Buffalo Lake, September 1996 - 2002

		Nutrients					*pH*
Site	Volume m3	TP kg	TDP kg	NO2+NO3 kg	NH3-N kg	TKN kg	pH units
Pariby Bay							
1996	539,829	19	--	--	--	--	8.81
1997	566,221	17	5	2	17	266	8.33
1998	559,448	31	10	1	11	442	9.00
1999	614,080	54	26	1	18	712	8.52
2000	616,656	49	12	1	55	444	8.28
2001	570,272	16	5	2	3	165	8.32
2002	545,702	14	6	1	3	251	8.60
Secondary Bay							
1996	40,260,459	5,930	--	2,738	3,623	79,716	9.12
1997	42,228,735	6,368	1,326	549	6,334	118,240	9.04
1998	41,723,627	4,573	1,510	63	1,669	72,599	9.11
1999	45,798,074	4,397	1,140	321	1,374	96,176	8.93
2000	45,990,237	4,861	1,067	69	1,380	85,542	8.91
2001	42,530,909	4,900	1,774	510	3,402	69,751	9.18
2002	40,698,452	3,754	212	2,116	1,221	91,979	9.09
Main Bay							
1996	229,114,293	17,825	--	--	--	--	9.29
1997	240,315,362	23,719	9,877	6,248	14,419	720,946	9.23
1998	237,440,895	13,653	8,263	356	14,246	384,654	9.22
1999	260,627,761	17,697	7,715	14,856	23,456	612,475	9.05
2000	261,721,325	16,567	10,809	1,309	20,938	450,161	9.00
2001	242,034,972	17,620	7,237	1,694	19,363	416,300	9.23
2002	231,606,824	13,039	7,666	4,401	25,477	590,597	9.25

Note: non-significant digits retained

Table B2. Change in Substance Mass in Buffalo Lake, June to September 1996 - 2002

Major Ions and Related Variables

Site	Volume m^3	Ca kg	Mg kg	K kg	Na kg	SO4 kg	Cl kg	HCO3 kg	CO_3^{2-} kg	TDS kg
Parlby Bay										
1996	-26,561	-7,331	-7,809	-2,469	-24,523	-17,033	-1,447	-97,067	13,766	-114,829
1997	-10,938	-17,264	-11,775	-4,532	-42,502	-36,508	-3,370	-180,039	7,741	-198,332
1998	3,477	295	-9,339	-2,152	-54,650	-28,332	-2,551	-87,951	-16,591	-167,886
1999	22,777	4,698	4,909	2,093	18,321	-6,828	1,294	64,122	467	60,303
2000	-11,582	-9,337	-6,060	-1,890	-15,973	-30,515	-3,637	-69,222	-3,462	-106,485
2001	-28,880	-3,064	-6,475	-3,222	-40,748	-21,386	-2,683	-92,804	-23,031	-146,512
2002	-26,248	-2,357	-3,209	-500	-10,909	-6,785	-2,418	-40,510	-818	-47,175
Secondary Bay										
1996	-1,980,929	116,675	393,116	233,617	2,837,068	6,434,812	34,837	2,782,553	815,700	4,587,944
1997	-815,767	-212,343	-247,032	-121,292	2,043,588	-190,456	73,853	2,197,922	212,393	2,740,089
1998	259,282	-14,304	133,265	200,252	1,150,952	-1,066,623	-21,145	61,274	33,447	386,330
1999	1,698,705	-20,990	196,216	181,900	828,566	762,317	113,340	-2,089,548	1,479,689	2,496,427
2000	-863,807	228,179	147,571	-301,209	-3,590,754	-456,060	-7,322	-2,092,556	-13,404	1,584,637
2001	-2,153,835	-61,539	-23,822	27,658	3,747,398	153,292	66,751	-848,241	1,552,592	5,189,276
2002	-1,957,599	-124,259	-659,106	-213,897	601,021	-792,417	-39,853	-1,344,656	-936,985	-5,534,914
Main Bay										
1996	-11,273,077	154,234	1,677,031	1,446,216	12,872,659	-1,459,769	86,677	-7,716,326	1,809,424	-9,053,980
1997	-4,642,367	53,981	-1,400,212	-382,234	-8,067,716	4,570,130	841,706	-7,231,215	8,550,600	745,694
1998	1,475,522	-488,445	1,158,208	1,151,544	9,312,193	-483,380	-46,148	525,758	5,265,132	14,557,495
1999	9,666,996	-50,116	-1,369,664	-956,984	-6,807,367	6,067,062	114,147	-6,298,585	3,439,164	-1,520,040
2000	-4,915,754	839,141	901,916	393,040	-3,734,616	5,432,298	383,067	-2,442,679	576,555	-9,044,987
2001	-12,257,046	-187,413	-609,743	-201,687	24,644,619	827,302	-31,695	-12,110,830	8,322,771	26,477,236
2002	-11,140,310	-39,225	-2,455,891	-206,675	14,414,315	-1,950,059	-138,842	-12,799,658	6,034,141	-26,132,935

Note: non-significant digits retained

Table B2. Change in Substance Mass in Buffalo Lake, June to September 1996 - 2002

		Nutrients					*pH*
Site	**Volume** m^3	**Total P** kg	**TDP** kg	**NO_2+NO_3** kg	**NH3** kg	**TKN** kg	**pH** units
Parlby Bay							
1996	-26,561	-13	--	--	--	--	0.23
1997	-10,938	-7	-10	1	0	-496	-0.26
1998	3,477	-4	-6	-4	-17	-425	-0.25
1999	22,777	32	12	0	1	446	-0.04
2000	-11,582	8	-20	0	30	-278	0.10
2001	-28,880	-22	-15	1	-33	-715	-0.54
2002	-26,248	-6	-5	0	0	-172	0.10
Secondary Bay							
1996	-1,980,929	3,126	--	2,400	667	-6,457	0.09
1997	-815,767	3,325	-374	-441	1,599	27,847	0.08
1998	259,282	1,347	-940	-1,057	-4,965	-18,622	0.06
1999	1,698,705	886	-1,007	-1,311	-10,092	76,772	0.15
2000	-863,807	2,078	-404	-1	-3,306	17,603	0.03
2001	-2,153,835	2,773	478	443	1,615	-16,044	0.16
2002	-1,957,599	1,353	-1,047	2,052	-1,765	7,520	-0.07
Main Bay							
1996	-11,273,077	1,335	--	--	--	--	0.10
1997	-4,642,367	7,282	-1,048	369	-2,728	133,048	0.04
1998	1,475,522	-2,794	-373	-2,239	89	-181,663	0.09
1999	9,666,996	3,241	-1,621	-3,966	870	-14,927	0.03
2000	-4,915,754	178	1,512	909	2,273	-84,891	-0.04
2001	-12,257,046	3,973	-1,579	974	15,125	-43,968	0.15
2002	-11,140,310	-227	-344	4,036	-3,653	12,859	0.03

Note: non-significant digits retained

Table B3. Summary of mass loads in Buffalo Lake Diversion, May to October (1997 - 2002)

Major Ions and Related Variables

	Volume	Ca	Mg	K	Na	SO4	Cl	HCO3	CO_3^{2-}	TDS
	Mm^3	kg	kg	kg	kg	kg	kg	kg	kg	kg
Parlby Crk @ Mirror										
1997	16.25	619,556	333,613	49,871	449,324	691,800	79,134	3,438,596	165,128	4,108,653
1998	12.58	477,477	256,794	47,482	336,058	373,003	47,537	2,756,689	89,799	3,016,771
1999*	27.99	540,164	295,044	47,770	463,297	518,193	97,636	3,405,614	23,664	3,740,846
2000*	21.01	606,403	312,762	81,104	349,530	685,470	84,145	3,293,682	10,062	3,763,243
2001*	8.34	241,576	147,486	15,926	118,698	332,131	29,892	1,274,569	7,420	1,524,572
2002*	21.30	501,961	303,593	35,948	273,818	742,481	86,621	2,644,980	107,080	3,397,268
Alix Lake Outflow										
1997	13.93	430,052	235,259	28,862	175,369	441,544	44,657	2,240,822	59,893	2,535,516
1998	10.46	327,241	169,355	27,494	123,468	266,549	28,418	1,643,784	36,700	1,825,660
1999	13.14	436,603	251,748	34,689	227,885	452,854	86,210	2,463,060	13,980	2,747,366
2000	15.36	490,143	252,799	65,555	282,518	554,051	68,013	2,662,214	8,133	3,041,750
2001	6.78	195,261	119,210	12,873	95,941	268,455	24,161	1,030,207	5,998	1,232,280
2002	15.39	405,725	245,388	29,056	221,321	600,132	70,014	2,137,882	86,551	2,745,940
Red Deer River @ Pumphouse										
1997	13.93	626,696	210,182	23,655	149,147	417,719	48,988	2,535,749	97,862	2,843,143
1998	10.46	394,420	139,571	20,876	82,486	245,704	17,273	1,665,431	33,530	1,783,665
1999**	13.14	634,686	229,710	28,636	188,652	437,844	44,795	2,835,318	21,927	2,475,416
2000**	15.36	670,246	247,165	37,458	239,910	517,080	59,040	3,107,963	15,612	3,318,652
2001**	6.78	267,681	101,940	11,618	84,497	270,110	26,555	1,151,547	12,905	1,351,207
2002**	15.39	522,991	211,071	17,796	115,046	591,052	37,190	2,058,288	98,880	2,608,200
1997 to 2002 (SUM)		Ca	Mg	K	Na	SO4	Cl	HCO3	CO_3^{2-}	TDS
Parlby Creek load @ Mirror		2,987,138	1,649,293	278,101	1,990,725	3,343,079	424,964	16,814,129	403,153	19,551,353
Diversion load @ Pumphouse		3,116,720	1,139,639	140,038	859,737	2,479,510	233,841	13,354,295	280,717	14,380,283
Pumphouse/Mirror		1.04	0.69	0.50	0.43	0.74	0.55	0.79	0.70	0.74
Total lake change (diversion period)		159,217	-2,197,907	1,237,577	50,080,942	17,701,062	1,414,560	-49,910,260	37,119,293	6,757,357
Annual Lake Change (diversion period)										
	Volume	Ca	Mg	K	Na	SO4	Cl	HCO3	CO_3^{2-}	TDS
1997	-5,469,072	-175,626	-1,659,019	-508,058	-6,066,630	4,343,165	912,188	-5,213,333	8,770,734	3,287,452
1998	1,738,281	-502,453	1,282,133	1,349,644	10,408,495	-1,578,335	-69,844	499,081	5,281,989	14,775,939
1999	11,388,478	-66,408	-1,168,539	-772,991	-5,960,480	6,822,551	228,781	-8,324,011	4,919,319	1,036,690
2000	-5,791,143	1,057,983	1,043,426	89,940	-7,341,343	4,945,723	372,109	-4,604,458	559,689	-7,566,835
2001	-14,439,760	-252,016	-640,039	-177,251	28,351,268	959,208	32,373	-13,051,875	9,852,333	31,520,001
2002	-13,124,158	-165,840	-3,118,206	-421,072	15,004,427	-2,749,260	-181,113	-14,184,824	5,096,339	-31,715,024

* Estimated based on Parlby Creek / Alix Lake

** Data for Red Deer River at Nevis

Note: non-significant digits retained

Table B3. Summary of mass loads in Buffalo Lake Diversion, May to October (1997 - 2002)

		Nutrients					*pH*
	Volume	TP	TDP	TKN	NH_3 N	NO_2+NO_3 N	Mean pH
	Mm^3	kg	kg	kg	kg	kg	pH Units
Parlby Crk @ Mirror							
1997	16.25	968	582	9,262	330	95	8.6
1998	12.58	666	473	9,361	193	35	8.6
1999*	27.99						
2000*	21.01						
2001*	8.34						
2002*	21.30						
Alix Lake Outflow							
1997	13.93	322	64	6,015	181	69	8.4
1998	10.46	322	88	6,915	182	22	8.2
1999	13.14	354	123	8,556	166	20	8.2
2000	15.36	309	107	7,762	237	23	8.1
2001	6.78	158	45	2,320	38	44	8.3
2002	15.39	321	113	7,757	172	33	8.5
Red Deer River @ Pumphouse							
1997	13.93	437	110	4,784	184	936	8.4
1998	10.46	551	80	4,258	434	360	8.3
1999**	13.14	446	141	5,320	82	133	8.4
2000**	15.36	706	214	6,647	158	380	8.3
2001**	6.78	357	39	2,289	130	208	8.4
2002**	15.39	164	88	3,229	93	70	8.8

1997 to 2002 (SUM)	**Total P**	**TDP**	**TKN**	**NH3**	**NO_2+NO_3**
Parlby Creek load @ Mirror	2,104	1,055	18,623	523	130
Diversion load @ Pumphouse	2,661	672	26,527	1,081	2,087
Pumphouse/Mirror	1.26	0.64	1.42	2.07	16.11
Total lake change (diversion period)	27,863	-6,793	2,167	-4,291	-92,564

Annual Lake Change (diversion period)

	Volume	**Total P**	**TDP**	**TKN**	**NH3**	**NO_2+NO_3**
1997	-5,469,072	10600	-1433	-70	-1129	160399
1998	1,738,281	-1451	-1320	-3300	-4893	-200710
1999	11,388,478	4159	-2616	-5277	-9221	62292
2000	-5,791,143	2264	1088	907	-1002	-67566
2001	-14,439,760	6724	-1116	1418	16707	-60728
2002	-13,124,158	1120	-1396	6089	-5418	20207

* Estimated based on Parlby Creek / Alix Lake

** Data for Red Deer River at Nevis

Note: non-significant digits retained

Table B4. Total estimated annual phosphorus loading to Buffalo Lake for 1997 through 2002. Loads in kilograms per year.

Source	1997		1998		1999		2000		2001		2002		Total	
	Load	% of Total Influx	Load	% of Total Influx	Load	% of Total Influx	Load	% of Total Influx	Load	% of Total Influx	Load	% of Total Influx	Load	% of Total
Watershed (Outside of Parlby Crk. Basin)	6,770	36	1,420	30	9,560	58	3,380	43	1,000	14	1,320	30	23,450	39
Watershed (Within Parlby Crk. Basin)	4,030	21	850	18	5,690	34	2,020	26	600	8	790	18	13,980	23
Total Watershed	10,800	57	2,270	48	15,250	92	5,400	69	1,600	22	2,110	48	37,430	63
Diversion	440	2	560	12	450	3	710	9	360	5	170	4	2,690	4
Atmospheric Deposition*	795	4	795	17	795	5	795	10	795	11	795	18	4,770	8
Internal Load (Secondary Bay)	3,390	--	1,150	--	-353	--	970	--	2,570	--	1,330	--	9,057	--
Internal Load (Main Bay)	3,530	--	-5,030	--	-5,388	--	-2,272	--	2,050	--	-2,523	--	-9,634	--
Total Internal Load to Lake**	6,920	37	1,150	24	0	0	970	12	4,620	63	1,330	30	14,990	25
Total External Load to Lake	12,040	100	3,630	100	16,500	100	6,910	100	2,760	100	3,080	100	44,890	100
Total Input Load***	18,955		4,775		16,495		7,875		7,375		4,405		59,880	
Total Net Load****	18,955		-255		10,753		5,603		7,375		1,882		44,313	
Total Annual Inflow (Mm3)	55.8	--	19.2	--	72.2	--	36.2	--	12.9	--	23.5	--	219.9	
Diversion Flow (Mm3)	13.9	--	10.5	--	13.1	--	15.4	--	6.8	--	15.4	--	75.1	

* From Shaw et al., 1989.

** Approximation: Includes bottom sediments, groundwater and sewage inputs; however, does not account for phosphorus mass that is sequestered into bottom sediments annually.

*** Sum of all input (watershed, diversion, atmospheric, and positive internal loads)

**** Sum of all watershed, diversion, atmospheric, and internal loads.

'Note: non-significant digits retained

Figure B1. Annual Mass Ratios of Major Ions in Buffalo Lake.

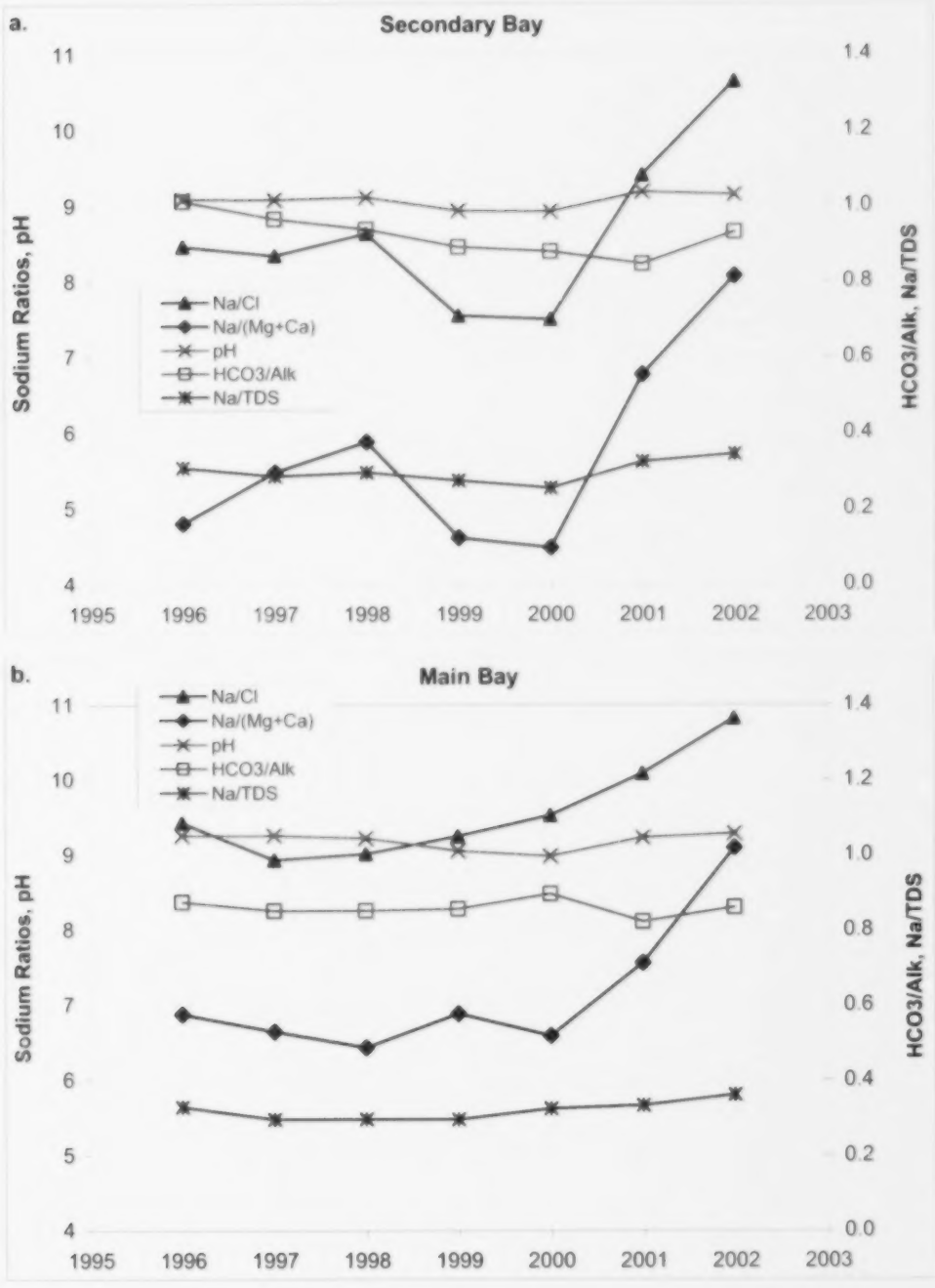


Figure B2. Scatterplots of Ion Concentrations (g/m^3) in Buffalo Lake: 1996 - 2002.

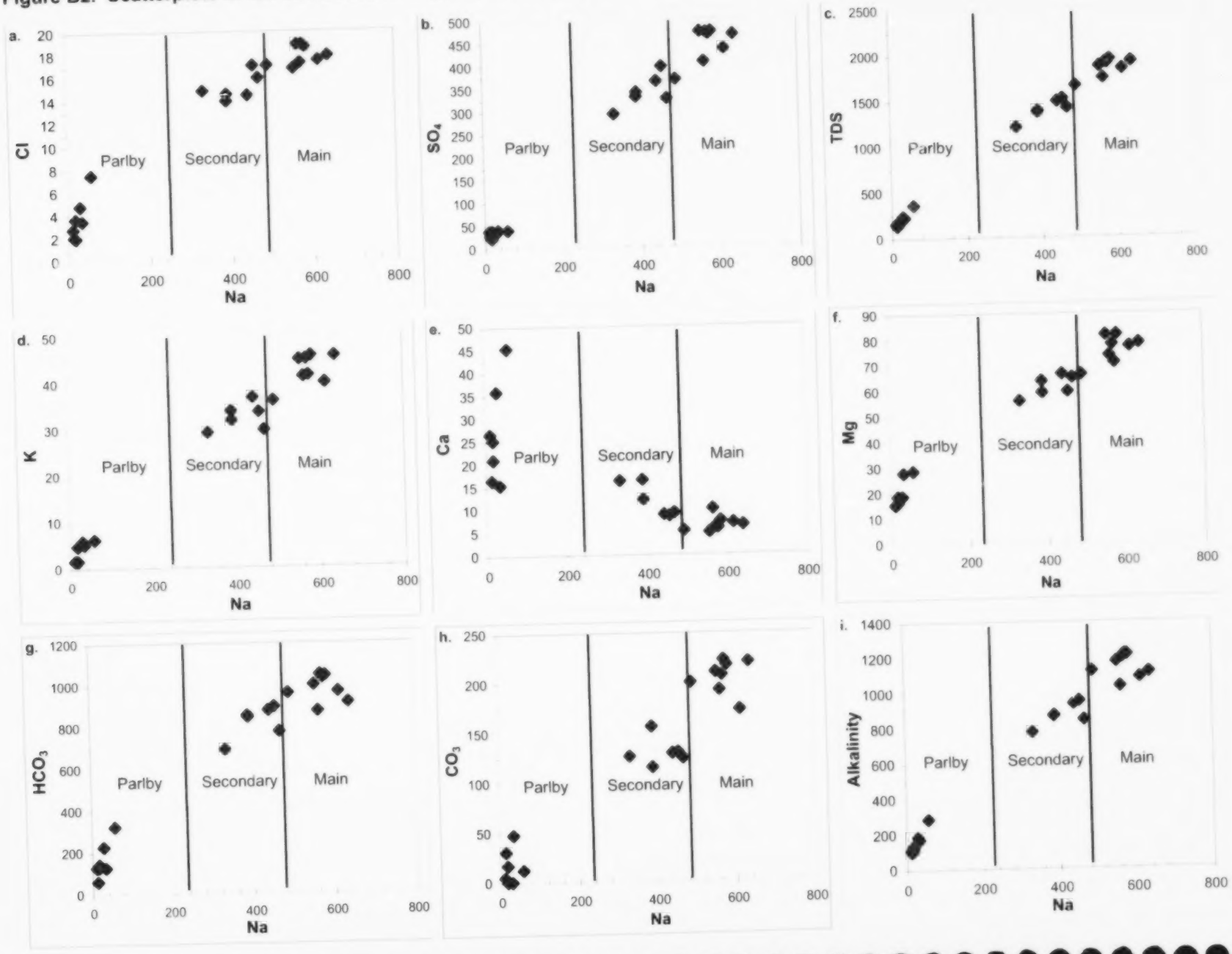


Figure B3. Total phosphorus concentrations in Alix Lake and Buffalo Lake: 1997 - 2002.

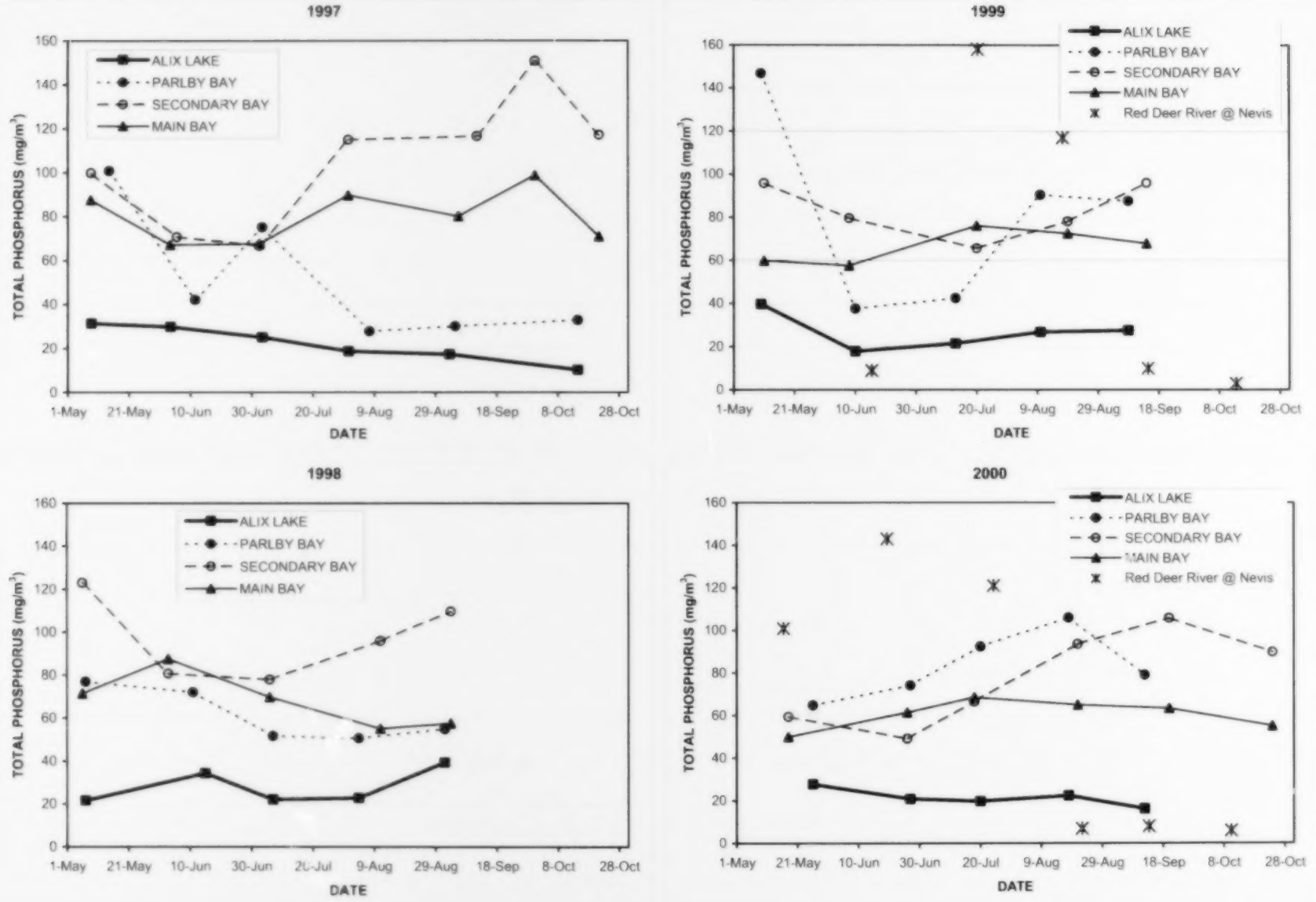
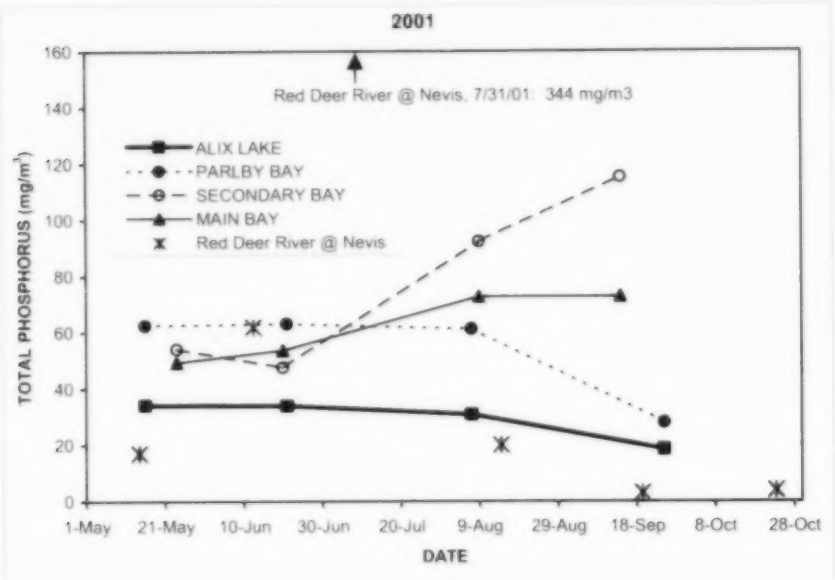


Figure B3. Total phosphorus concentrations in Alix Lake and Buffalo Lake: 1997 - 2002 (cont'd.)



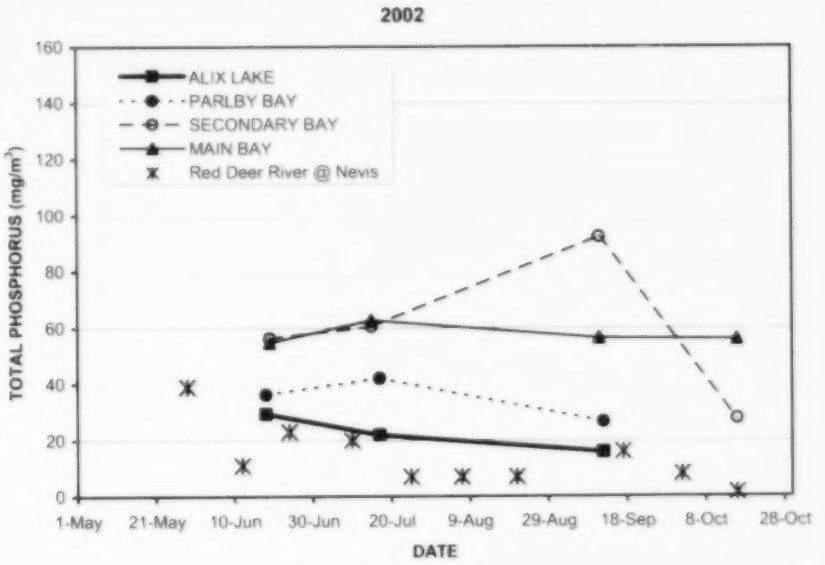


Figure B4. Chlorophyll *a* concentrations in Alix Lake and Buffalo Lake: 1997 - 2002.

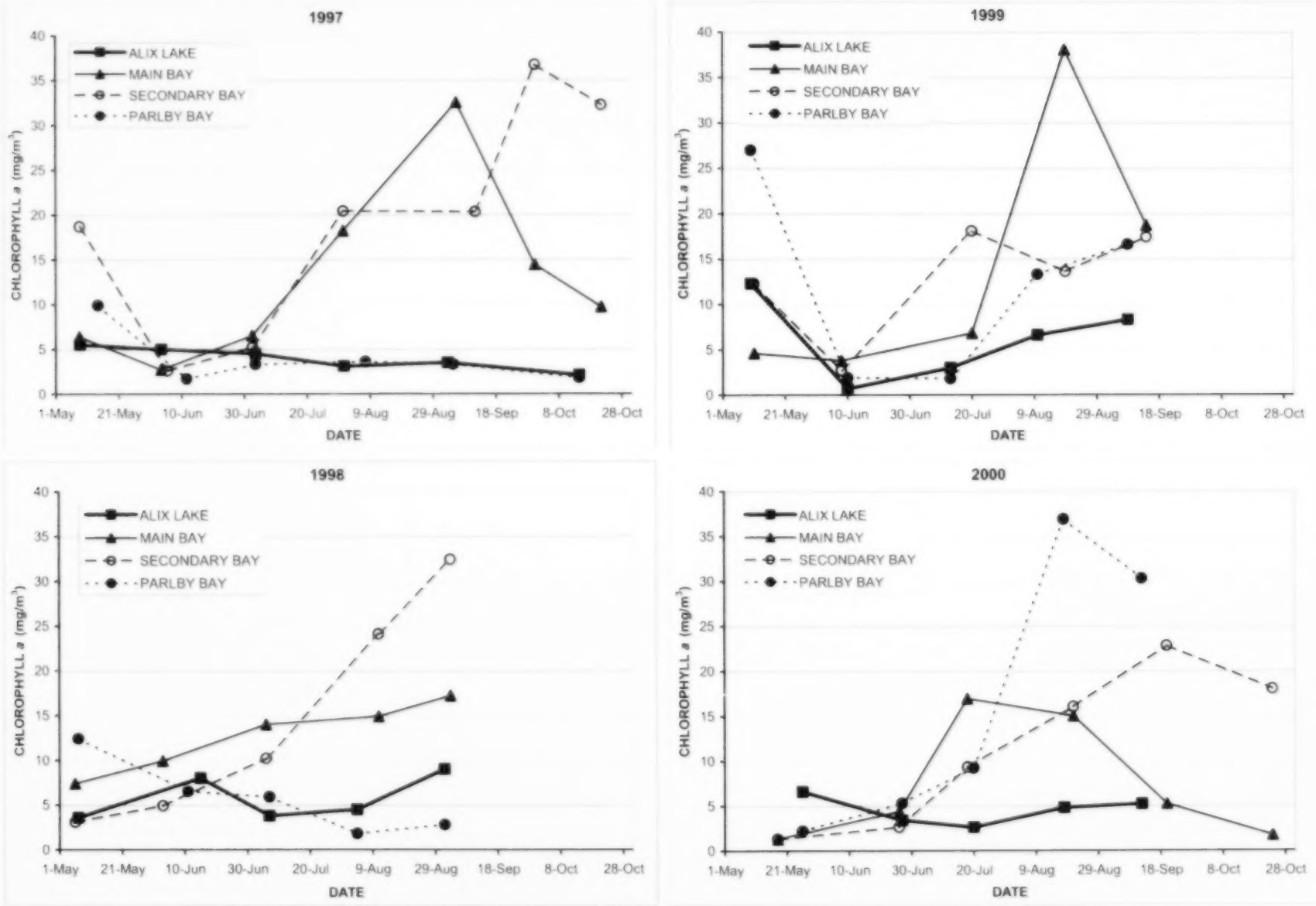
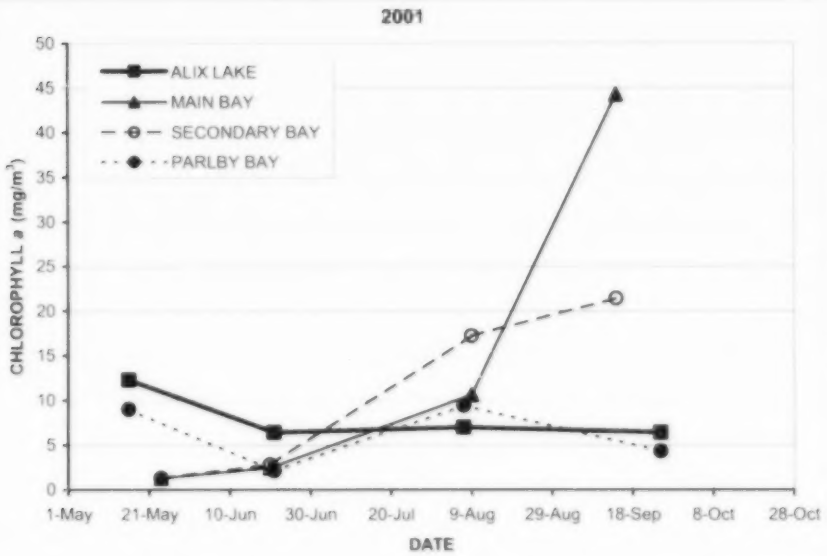


Figure B4. Chlorophyll a concentrations in Alix Lake and Buffalo Lake: 1997 - 2002 (cont'd.)



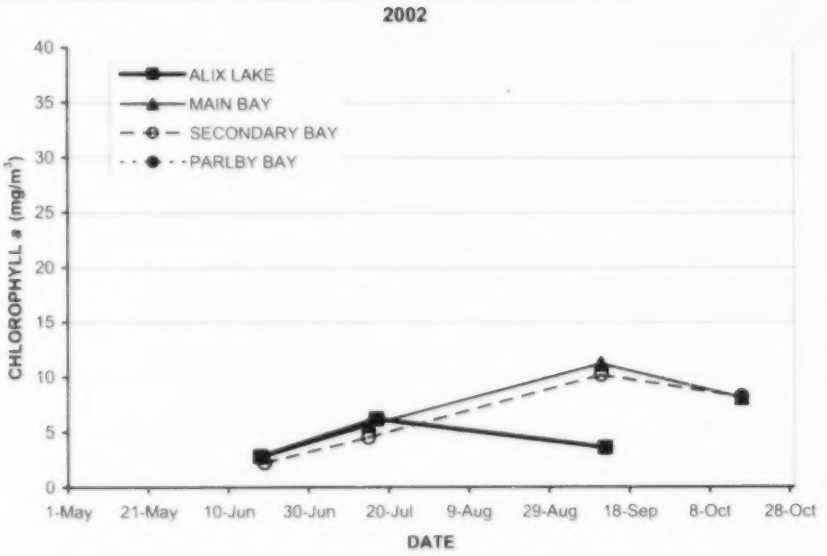


Figure B5. Relative annual total phosphorus loads to Buffalo Lake: 1997 – 2002.

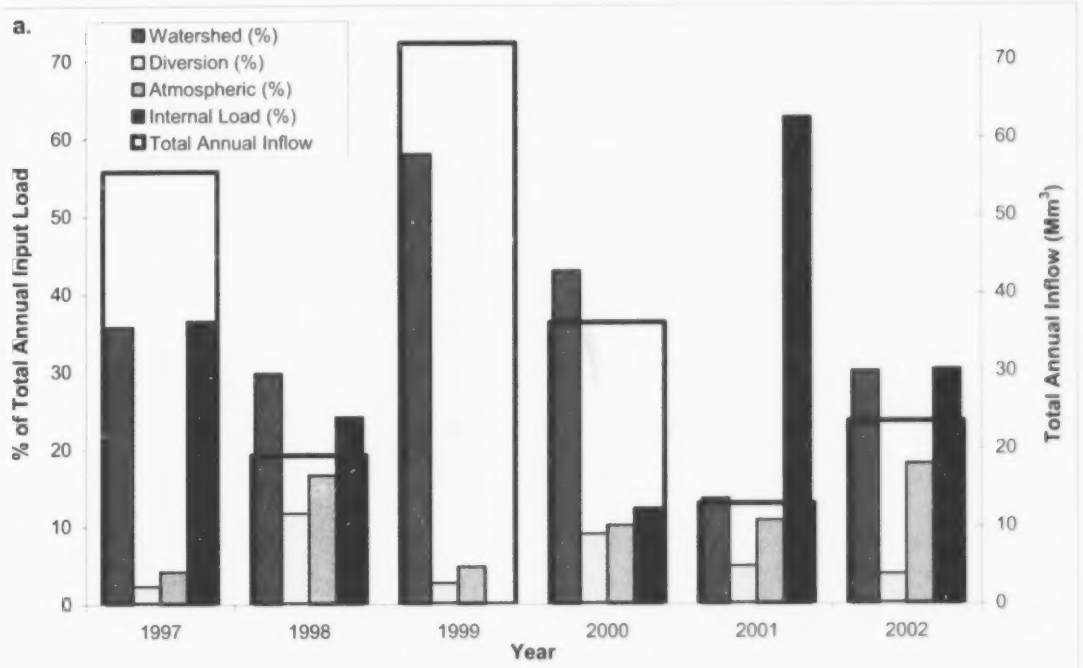


Figure B5. Average relative total phosphorus loads to Buffalo Lake: 1997 – 2002.